COMPARISON OF EFFLUX COEFFICIENTS FOR VARIOUS SHAPES & SIZES OF NOZZLES

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ARMOUR INSTITUTE OF TECHNOLOGY

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coefficients for various

Comparison of Efflux Coefficients for Various Shapes and Sizes of Nozzles

A THESIS

PRESENTED BY

SAMUEL J. AURELIUS
AND
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TO THE

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COMPARATIVE DISCUSSION OF COEFICIENTS OF EFFLUX: 80

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Part 1.

Calibration of a 1 1/2" Venturi Meter

INTRODUCTION.

In the calibration of nozzles it is necessary to determine the quantity of water flowing and the hydraulic head producing the flow. This water may be measured in a number of ways; for instance, by means of the rectangular weir, by the use of weighing tanks or some form of water meter. The reliability, simplicity and ease of application warranted the use of the venturi meter.

In order to make use of such a meter it is necessary to have its calibration curve. The coordinates of this calibration curve are the pressure differences and the discharge through the meter. From the curve then, for any pressure difference within its range, the corresponding flow may be obtained.

Apparatus for Calibration of Venturi Meter.

The water was drawn from a reservoir or sump by means of a two stage Kerr turbine and discharged through the venturi meter to weighing tanks. The discharge from these tanks was directly back into the sump so that the same water was used repeatedly.

Connections were made between the meter and manometer with half inch piping. As shown in the sketch, (A) and (B) lead from the throat and approach respectively. Provided a solid column of water is maintained in each pipe, the true lead producing the flow would be shown as the difference in the two legs of mercury in the manometer.

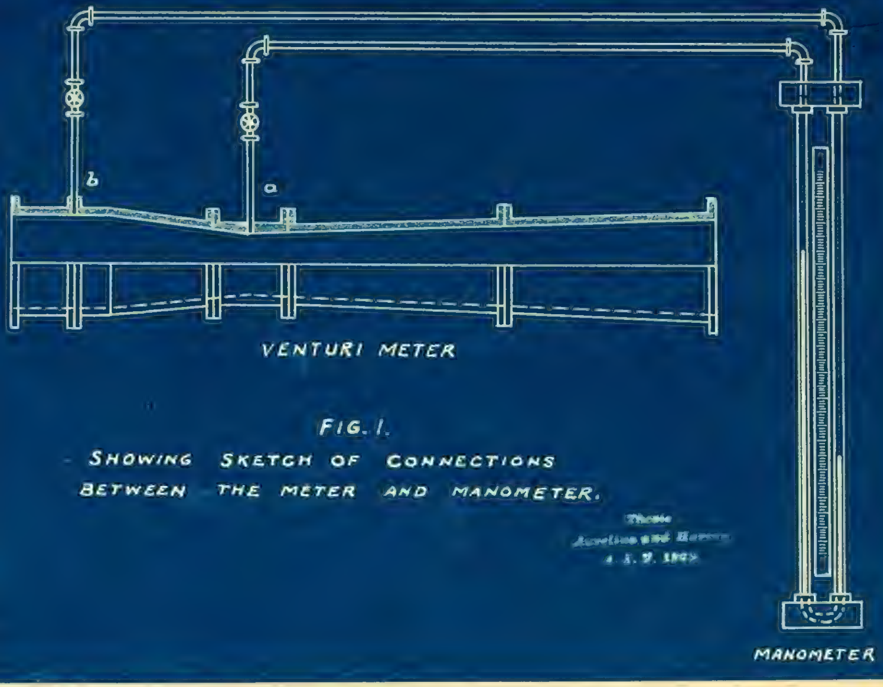

FIG. 1.

SHOWING SKETCH OF CONNECTIONS
BETWEEN THE METER AND MANOMETER.

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A. I. T. 19[illegible]

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METHOD OF CALIBRATION

The head was varied from a minimum to about twenty inches of Mercury; from five to ten minute runs being made for each head. The manometer was read every minute during the run and at the close the temperature and weight of the water were taken.

A series of runs were made and from the data curves were plotted. These curves are of the straight line type in which the square root of the head was plotted against the cubic feet discharged. The points, however, gave somewhat of a shot gun pattern and it was quite impossible to get a straight line. This was good evidence of some discrepencies in the work.

After investigation it was discovered that the suction water was taking up air. This air collected in the pipes leading to the manometer and due to its expansion and compression caused considerable variation in the height of the mercury.

This trouble was remedied by plading some pet cocks at the highest point of the system as shown in Fig. 2. These were opened before each reading and any entrained air allowed to escape. This assured a solid column of water and reliable readings.

A great deal of trouble was experienced in reading the mercury levels, due to the sediment brough in on the pressure side. This sediment, collecting on top of the mercury destroyed the form of the meniscus, which is essential for accurate readings. To overcome this difficulty a mud drum, equipped with a blow-off cock, was inserted in the system on the pressure side. The amount of sediment was greatly reduced by this means.

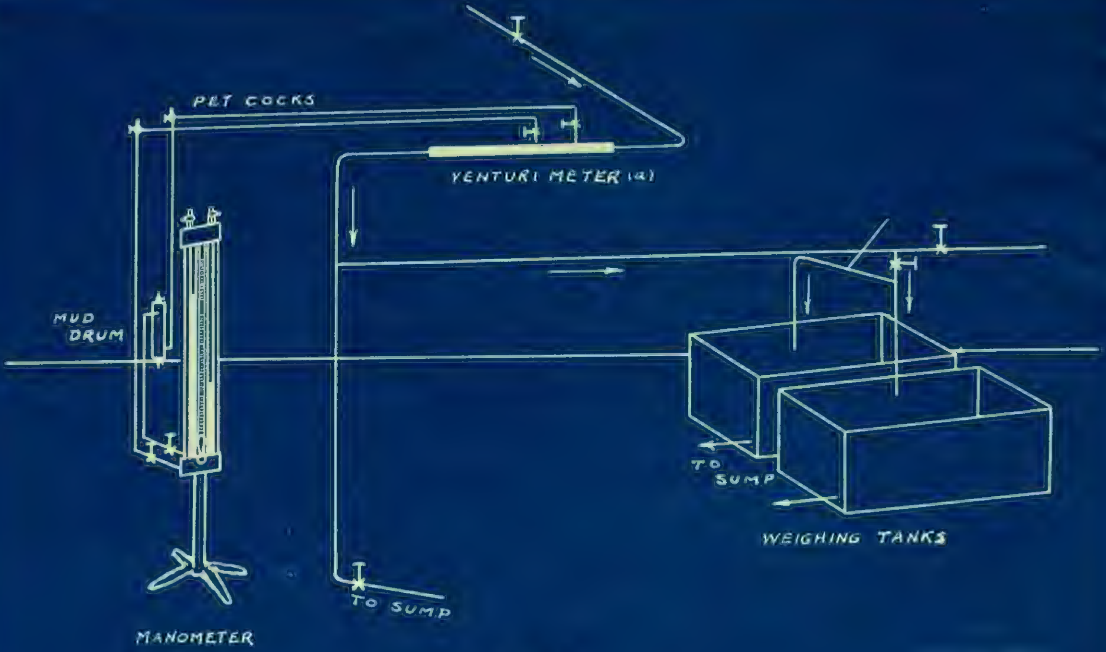


FIG. 2.

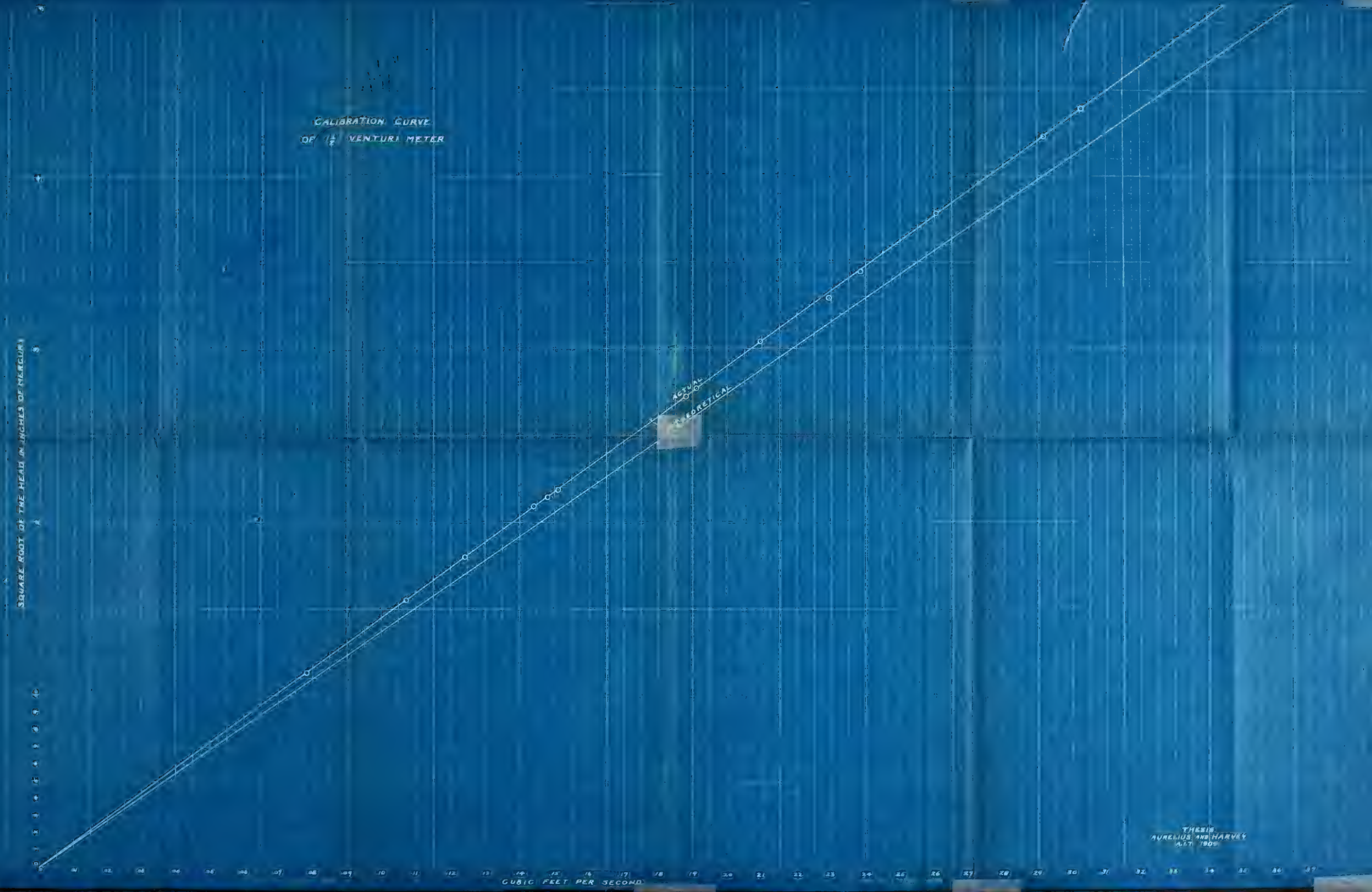
PLAN OF APPARATUS

DATA AND RESULTS

Point Number	Water Lbs. per sec.	Water Cu. ft. per sec.	Ins. of Hg. h	Ins. of Hg. $\sqrt{h}$
1	4.885	.0875	1.275	1.130
2	6.680	.1073	2.498	1.550
3	7.621	.1245	3.240	1.800
4	8.977	.1441	4.380	2.092
5	9.250	.1483	4.608	2.146
6	9.417	.1511	4.776	2.185
7	11.755	.1886	7.428	2.725
8	11.842	.1916	7.656	2.766
9	13.162	.2100	9.236	3.040
10	14.274	.2300	10.870	3.290
11	14.896	.2390	11.832	3.440
12	16.495	.2610	14.281	3.780
13	18.218	.2924	17.880	4.228
14	18.888	.3032	19.272	4.390

From the above data the square roat of the head, in inches of mercury, was plotted against the discharge, in cubic feet per second as shown in Plate 1.

The straight line curve was used beaause of its accuracy and convenience in reading. The theoretical curve was drawn in and its position with reference to the actual curve, gave the coefficient of the meter as 95 %, which compares favorably with previous results.



CALIBRATION CURVE
OF 1/2 VENTURI METER

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Part II

Calibration of Nozzles

INTRODUCTION

Theoretically, the discharge from a nozzle is

$$Q = F\sqrt{2\ gh}$$

in which F is the area of the nozzle (square feet) and h is the hydraulic head producing flow (feet). In practice, however, only a per cent of this is obtained and the equation takes the form

$$Q = C.F\sqrt{2\ gh}$$

in which C is the coefficient of efflux depending upon the form and proportions of the nozzle.

The nozzles investigated, in these tests for this efflux coefficient, were made of turned brass, 1, 15/16 inches long. They were designed with various openings at entrance and exist and were either of a straight bore or straight taper. A number were also made with a slightly rounded approach. The tapered ones without the rounded approach were reversed and made equivalent to two nozzles of either the converging or diverging type.

APPARATUS FOR CALIBRATION

A plan of the apparatus is shown in Fig. (3). The direction of flow is as indicated by arrows. The water after passing through the meter (a) was discharged into a length of eight inch pipe (b). A hole was bored at (c) and tapped to take a two inch nozzle holder, the form and proportions of which are shown in Fig. (4). The head was indicated by a pressure guage attached at the top of the pipe and directly in back of the nozzle.

This pipe served as a reservoir in which the water was practically at rest, due to the large supply in proportion to the discharge. Eddy currents and velocity of approach, which would effect the velocity head are avoided thru this arrangement.

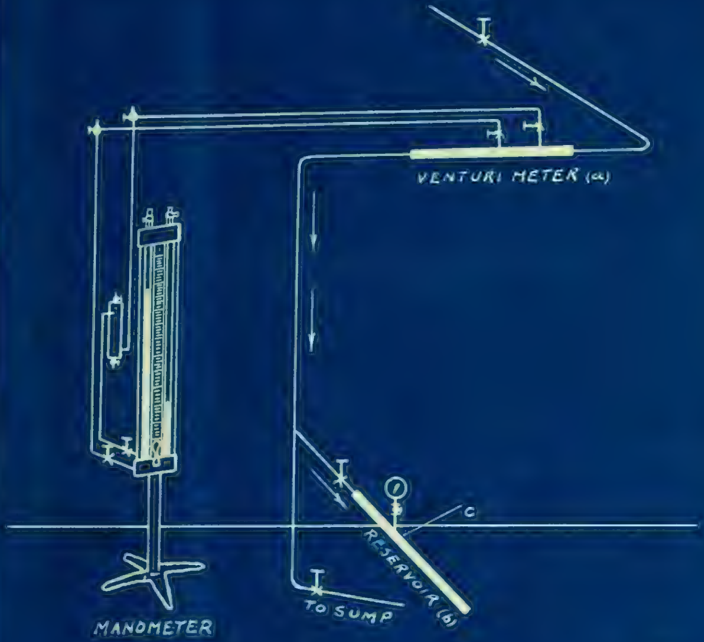

FIG. 3

SKETCH OF APPARATUS

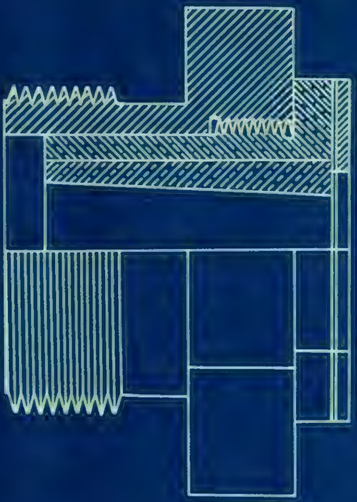

FIG. 4.

SKETCH OF NOZZLE HOLDER

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METHOD OF CALIBRATION.

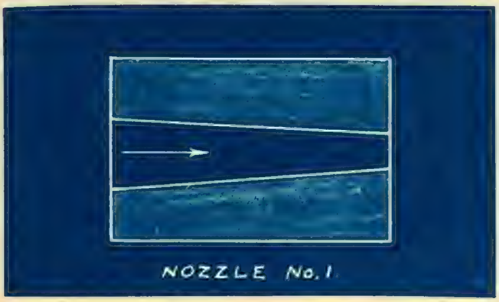
With the nozzle properly attached to the reservoir the pressure was varied from 150 pounds per square inch to 20 pounds per square inch. For each interval of 10 pounds a reading was taken of the manometer. In every case before reading the manometer all entrained air was liberated.

This range afforded about a dozen points in locating the characteristic curve for each nozzle. The calibrations and curves appear on the following pages.

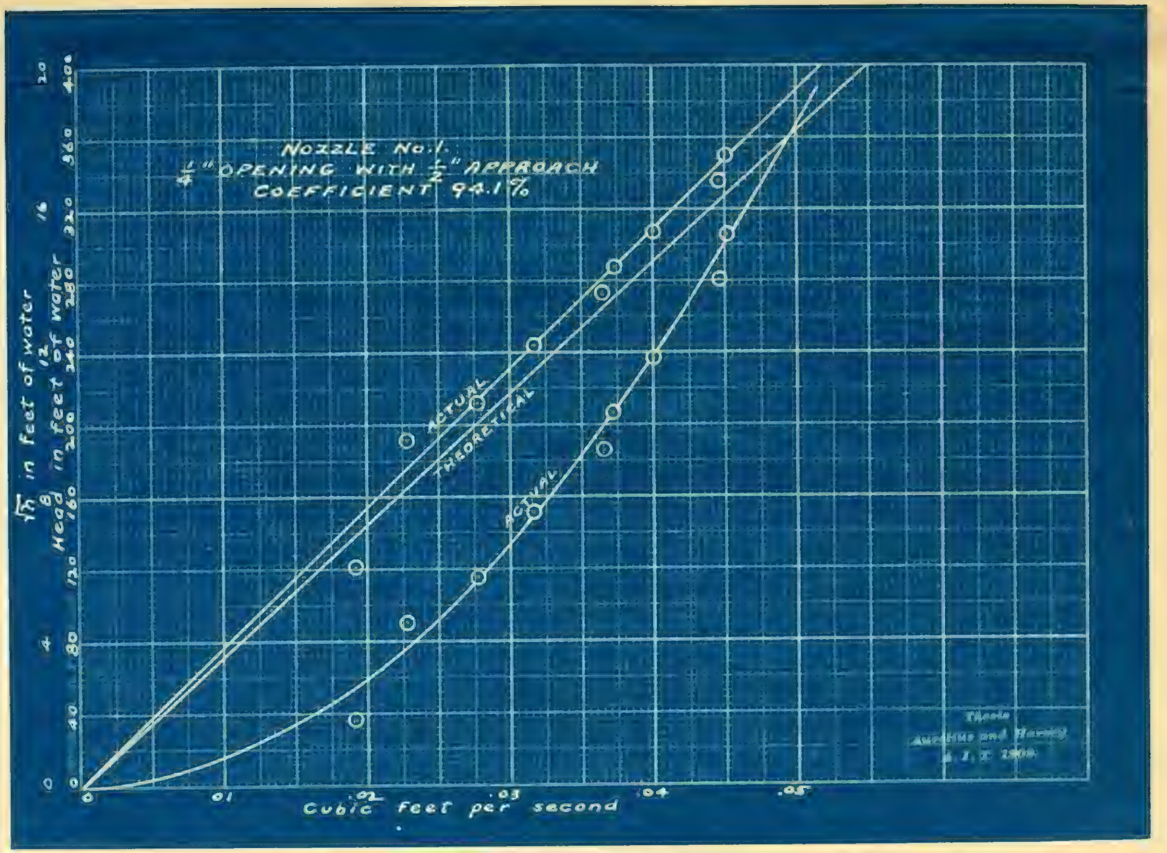
NOZZLE NO.I.

1/4" opening with 1/2" approach.

Meter	"hg	Nozzle	Pressure		Discharge
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft/sec.
.96	.980	157.5	363.6	19.10	.0683
.41	.640	133.0	307.0	17.52	.0450
.40	.633	122.5	282.6	16.81	.0446
.32	.565	103.0	237.9	15.42	.0400
.28	.529	90.0	207.7	14.42	.0373
.27	.519	81.0	187.0	13.69	.0365
.20	.447	65.5	152.2	12.33	.0317
.15	.387	50.0	115.5	12.29	.0277
.10	.316	40.0	92.38	9.51	.0227
.07	.264	16.0	36.94	6.08	.0191



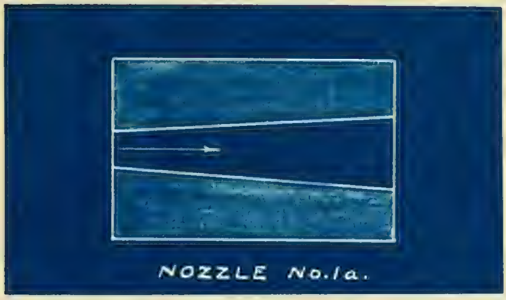
NOZZLE No. I


NOZZLE No. 1.
$\frac{1}{4}$" OPENING WITH $\frac{1}{2}$" APPROACH
COEFFICIENT 94.1%
ACTUAL
THEORETICAL
ACTUAL
$\sqrt{h}$ in feet of water
Head in feet of water
0
4
8
12
16
20
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second
0
.01
.02
.03
.04
.05

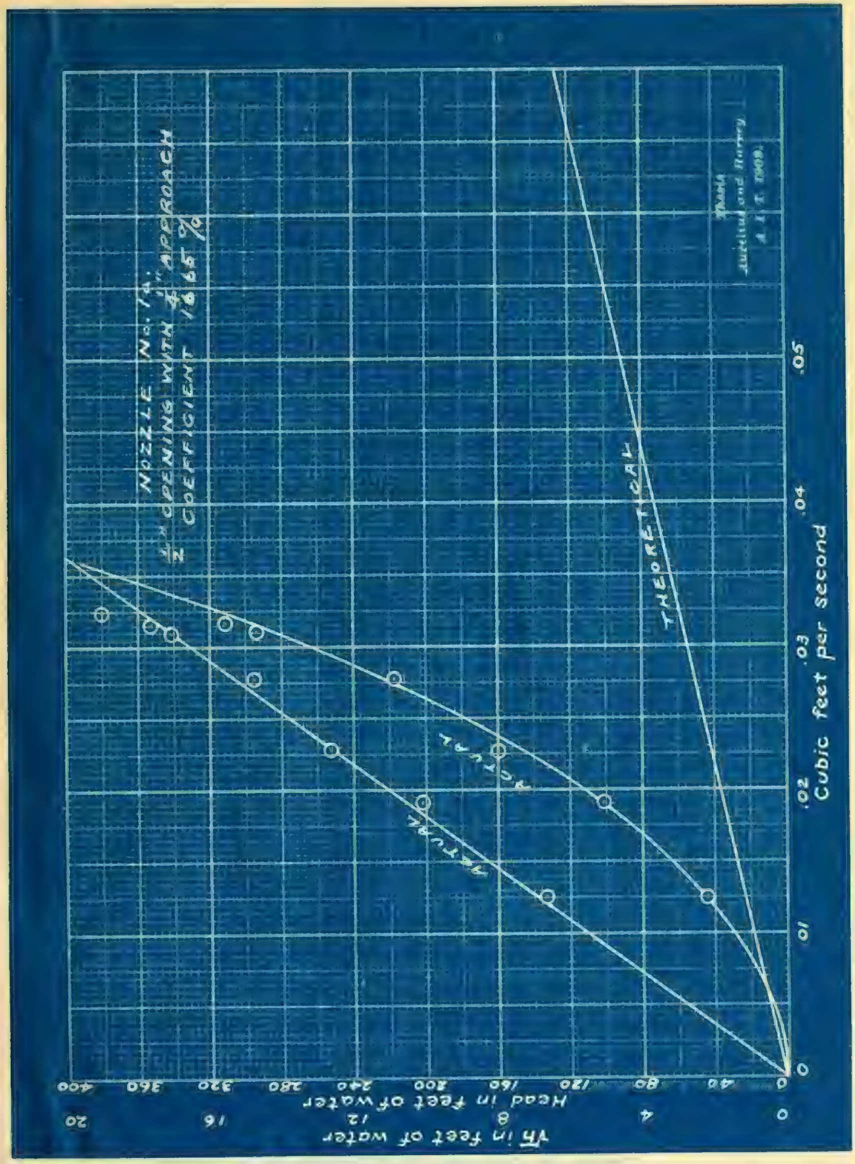
NOZZLE NO.I.(a)

1/2" opening with 1/4" approach

Meter	"Hg	Nozzle	Pressure		Discharge
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft./sec.
.21	.458	157.5	363.6	19.04	.0324
.20	.447	135.0	311.5	17.64	.0317
.19	.435	128.0	295.2	17.18	.0315
.15	.387	95.0	219.2	14.80	.0277
.10	.316	70.0	161.2	12.69	.0229
.07	.264	44.5	102.8	10.13	.0191
.03	.173	19.5	45.0	6.70	.0125



NOZZLE No.1a.


NOZZLE No. 7A.
1/2" OPENING WITH 3/4" APPROACH
COEFFICIENT 16.65 %
THEORETICAL
ACTUAL
ACTUAL
Cubic feet per second
0
.01
.02
.03
.04
.05
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
√h in feet of water
0
4
8
12
16
20
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A.I.T. 1909.

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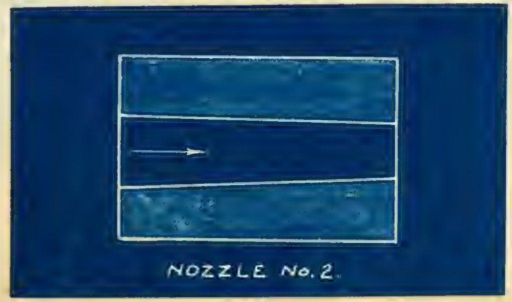
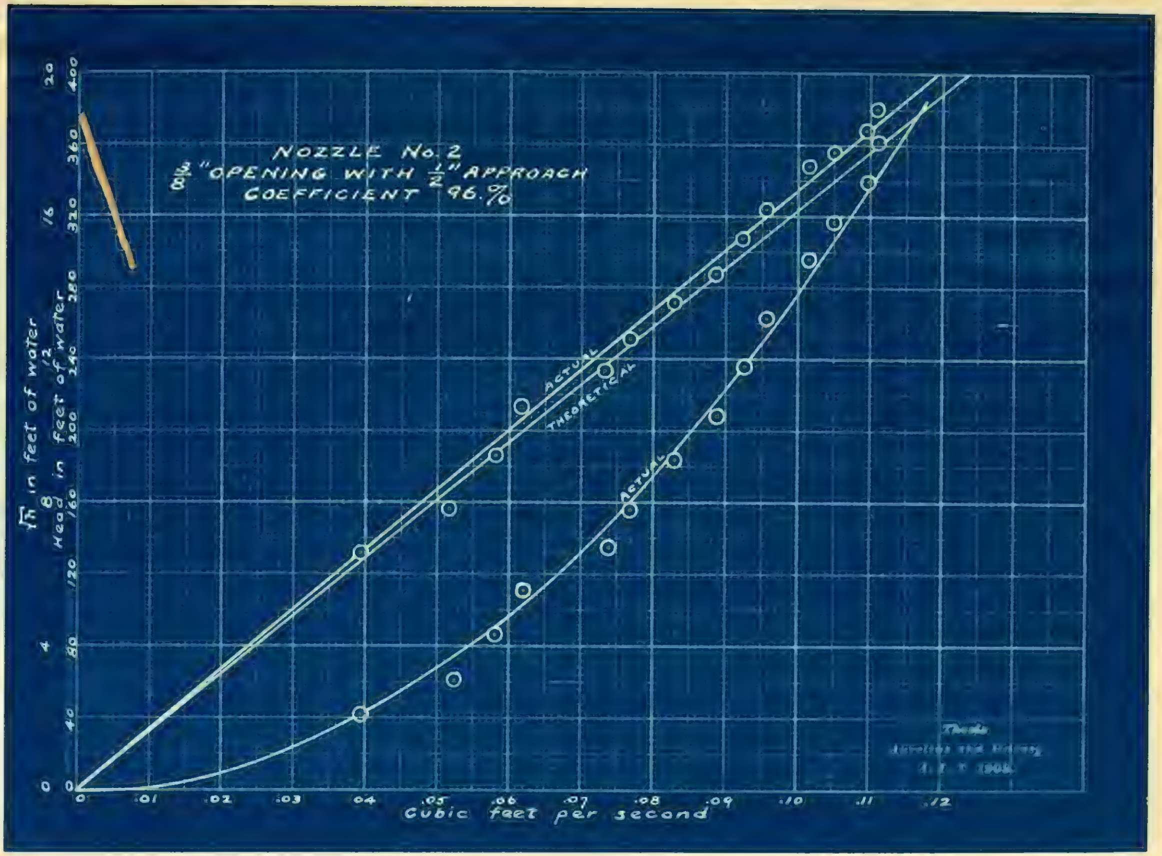
NOZZLE NO.2.

3/8" opening with 1/2" approach.

Meter	"Hg.	Nozzle Pressure			Discharge
h	$\sqrt{h}$	#/Sq.in.	Ft. H_2O	$\sqrt{h}$	Cu.ft/ Sec.
2.62	1.617	157.0	362.	19.05	.1120
2.50	1.580	147.0	340.	18.44	.1095
2.29	1.512	137.6	318.	17.83	.1050
2.14	1.463	128.0	297	17.42	.1015
1.89	1.374	114.0	264	16.23	.0955
1.76	1.327	102.0	237	15.36	.0922
1.63	1.276	90.5	209	14.47	.0886
1.42	1.191	80.5	186	13.65	.0829
1.21	1.100	88.5	158	12.59	.0766
1.01	1.050	59.0	136	11.68	.0832
.78	.883	48.5	112	10.66	.0617
.69	.883	38.0	88	9.38	.0580
.53	.727	27.0	62	7.91	.0510
.31	.550	19.0	44	6.63	.0393


NOZZLE No. 2.


NOZZLE No. 2
$\frac{3}{8}$" OPENING WITH $\frac{1}{2}$" APPROACH
COEFFICIENT 96.%

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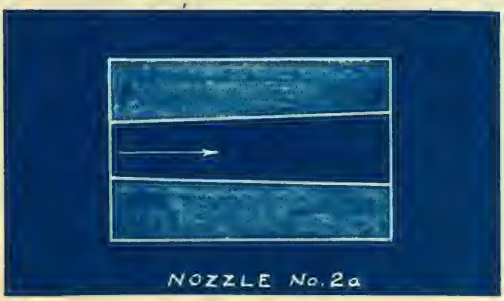
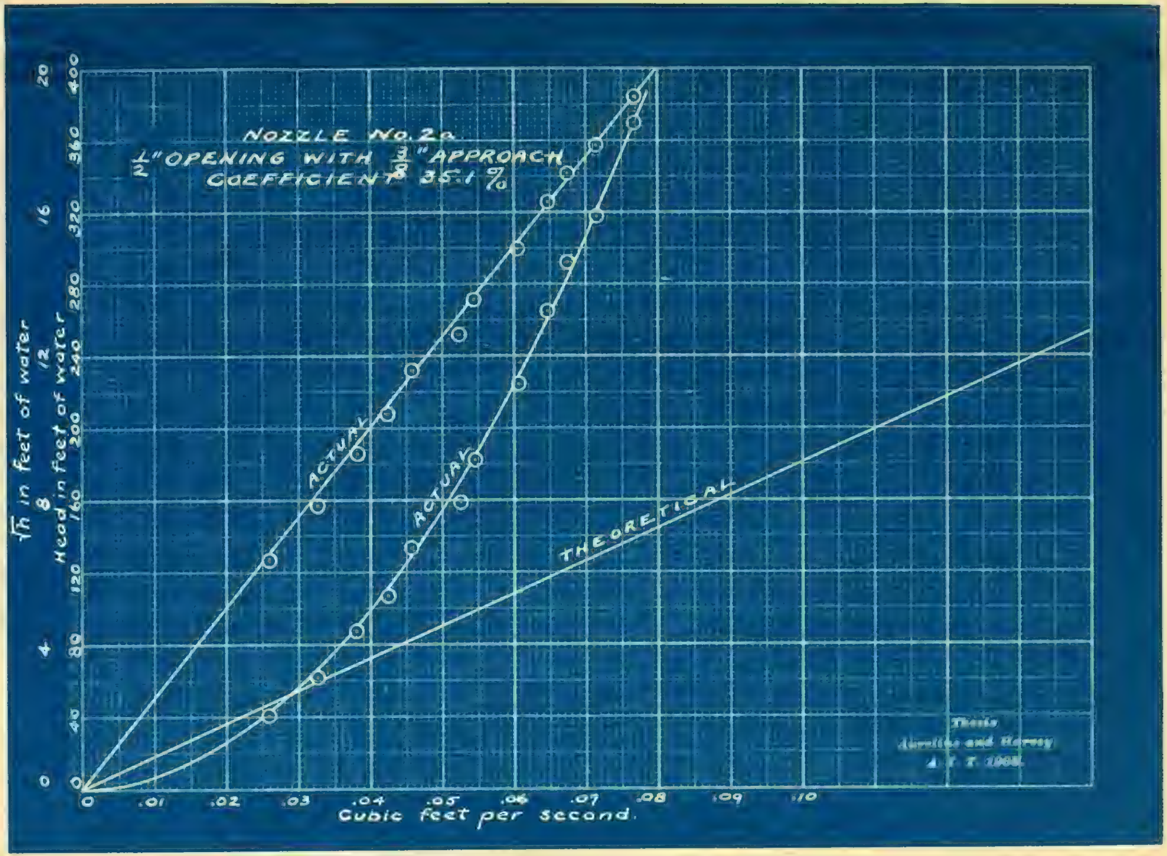
NOZZLE NO.2(a)

1/2" opening with 3/8 Approach.

Meter	"Hg	Nozzle	Pressure		Discharge
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft./Sec.
1.102	1.95	160.0	369	19.2	.0766
1.02	1.39	138.0	318	17.84	.0713
.93	.963	127.0	293	17.11	.0673
.86	.927	115.0	266	16.30	.0647
.74	.860	97.5	225	15.00	.0602
.60	.774	80.0	184	13.59	.0542
.55	.742	69.5	160	12.66	.0522
.42	.648	58.5	135	11.62	.0456
.36	.60	47.0	108	10.42	.0432
.29	.538	38.0	87.8	9.37	.0380
.21	.458	27.0	62.3	7.89	.0325
.13	.360	17.5	40.4	6.36	.0258

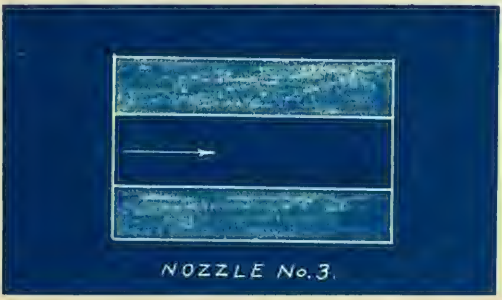



NOZZLE No. 2a
$\frac{1}{2}$" OPENING WITH $\frac{3}{8}$" APPROACH
COEFFICIENT 35.1 %
ACTUAL
ACTUAL
THEORETICAL
$\sqrt{h}$ in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second.
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
Thesis

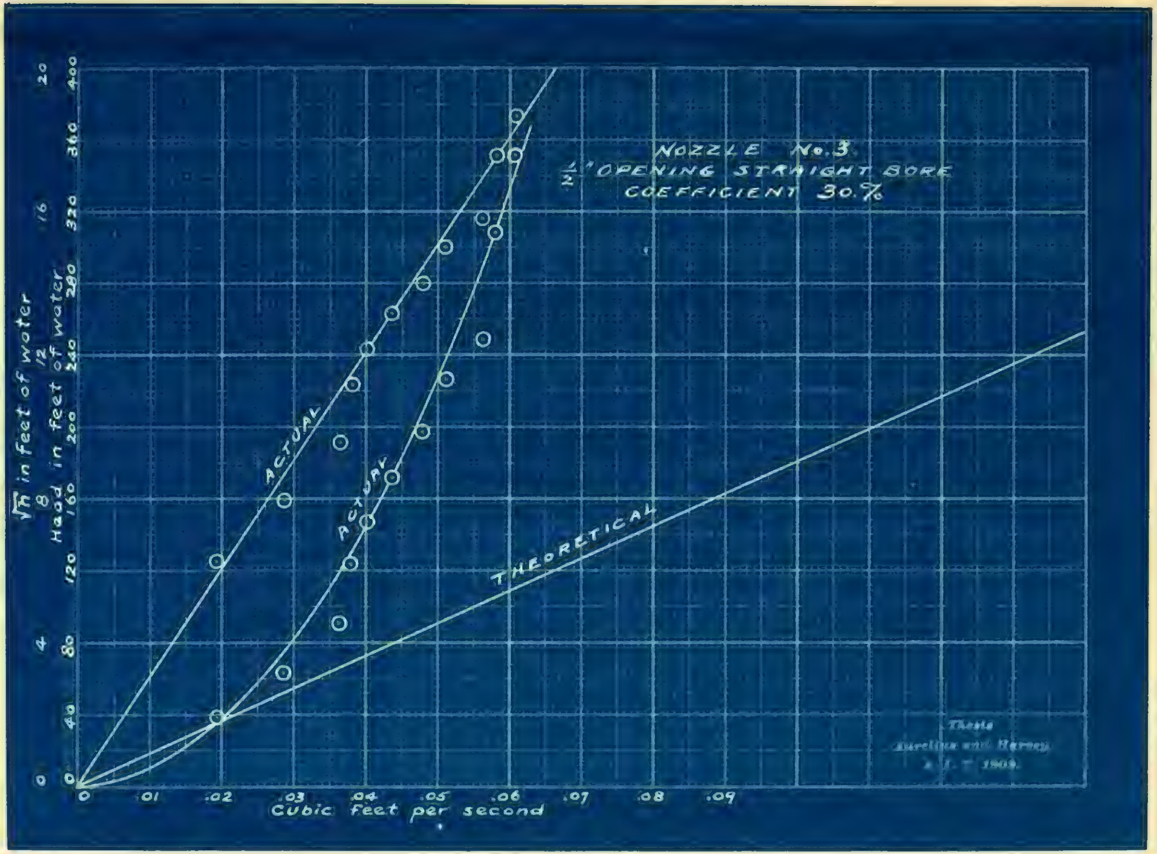
NOZZLE NO.3.

1/2" Straight Bore.

Meter	"Hg	Nozzle Pressure			Discharge.
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft./Sec.
.75	.866	152.	352.	18.74	.0606
.69	.83	133.5	309.	17.57	.058
.64	.80	108.	250.	15.8	.056
.53	.7275	98.	227.	15.06	.051
.46	.678	85.5	198.	14.06	.0478
.38	.617	75.	173.	13.16	.0435
.32	.565	64.5	149.	12.22	.040
.28	.539	54.	125.	11.17	.038
.26	.51	40.5	92.5	9.62	.0361
.16	.40	28.	64.8	8.05	.0285
.07	.265	17.	39.3	6.27	.0192



NOZZLE No.3.


NOZZLE No. 3
½" OPENING STRAIGHT BORE
COEFFICIENT 30.%
ACTUAL
ACTUAL
THEORETICAL
$\sqrt{h}$ in feet of water
Head in feet of water
Cubic feet per second
0
4
8
12
16
20
0
40
80
120
160
200
240
280
320
360
400
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
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M. I. T. 1909.

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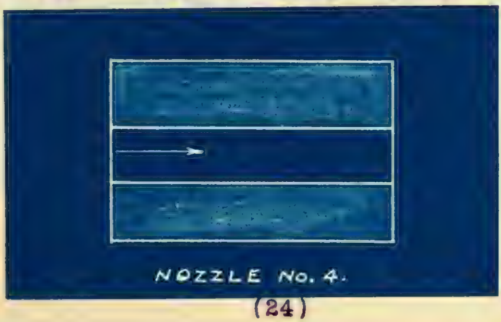
NOZZLE NO.4.

3/8" Straight Bore.

Meter "Hg		Nozzle Pressure			Discharge.
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.Ft./Sec.
1.25	1.117	157.	362.	19.05	.0777
1.22	1.104	146.	338.	18.38	.0768
1.16	1.076	135.	312.	17.66	.075
1.10	1.047	127.	294.	17.13	.0729
.97	.985	114.	264.	16.23	.0685
.81	.90	103.	238.	15.43	.0628
.70	.836	90.5	209.	14.47	.0585
.66	.812	80.5	186.	13.65	.0568
.54	.735	66.5	154.	12.41	.0516
.44	.663	54.5	126.	11.23	.0467
.27	.52	38.5	89.	9.45	.0368
.25	.50	24.5	56.6	7.52	.0353
.16	.40	14.	32.4	5.69	.0285



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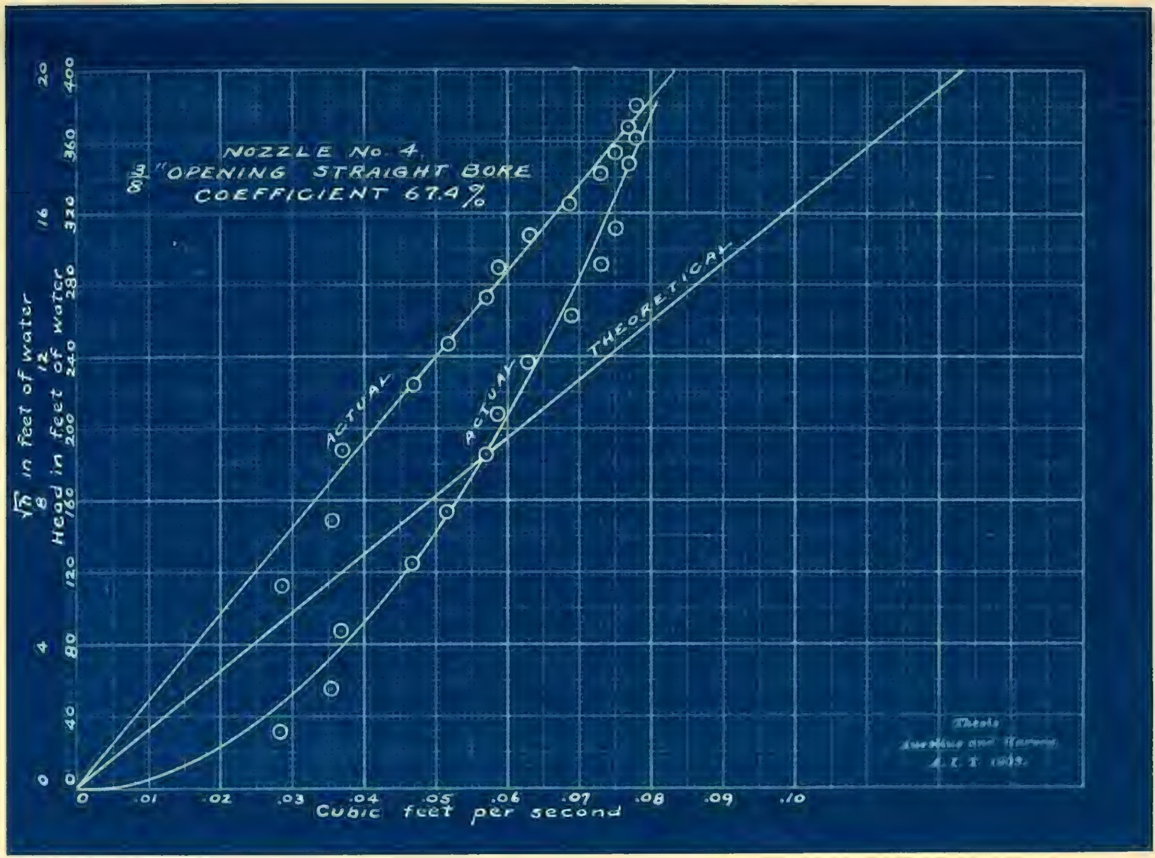
NOZZLE No. 4.
3/8" OPENING STRAIGHT BORE
COEFFICIENT 67.4%
ACTUAL
ACTUAL
THEORETICAL
√h in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
Thesis
A. I. T. 1912.

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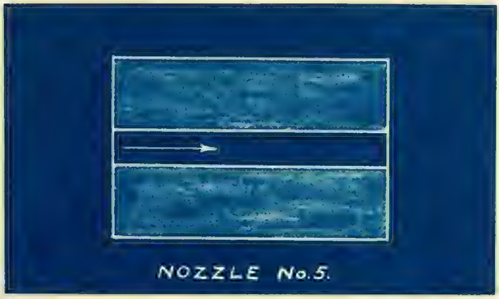
NOZZLE NO.5.

1/4" Straight Bore.

Meter	"Hg.		Nozzle Pressure		Discharge.
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft./Sec.
.29	.538	157.	362.	19.03	038
.24	.489	139.5	322.	17:92	.036
.20	.447	113.5	262.	16.19	.0318
.10	.316	55.5	128.	11.32	.0228
.04	.20	32.5	75.	8.65	.0172
.03	.173	17.5	40.4	6.36	.0124
.09	.30	43.	99.3	9.95	.0218
.14	.374	72.	166.	12.89	.027
.16	.40	86.5	199.	14.33	.0285



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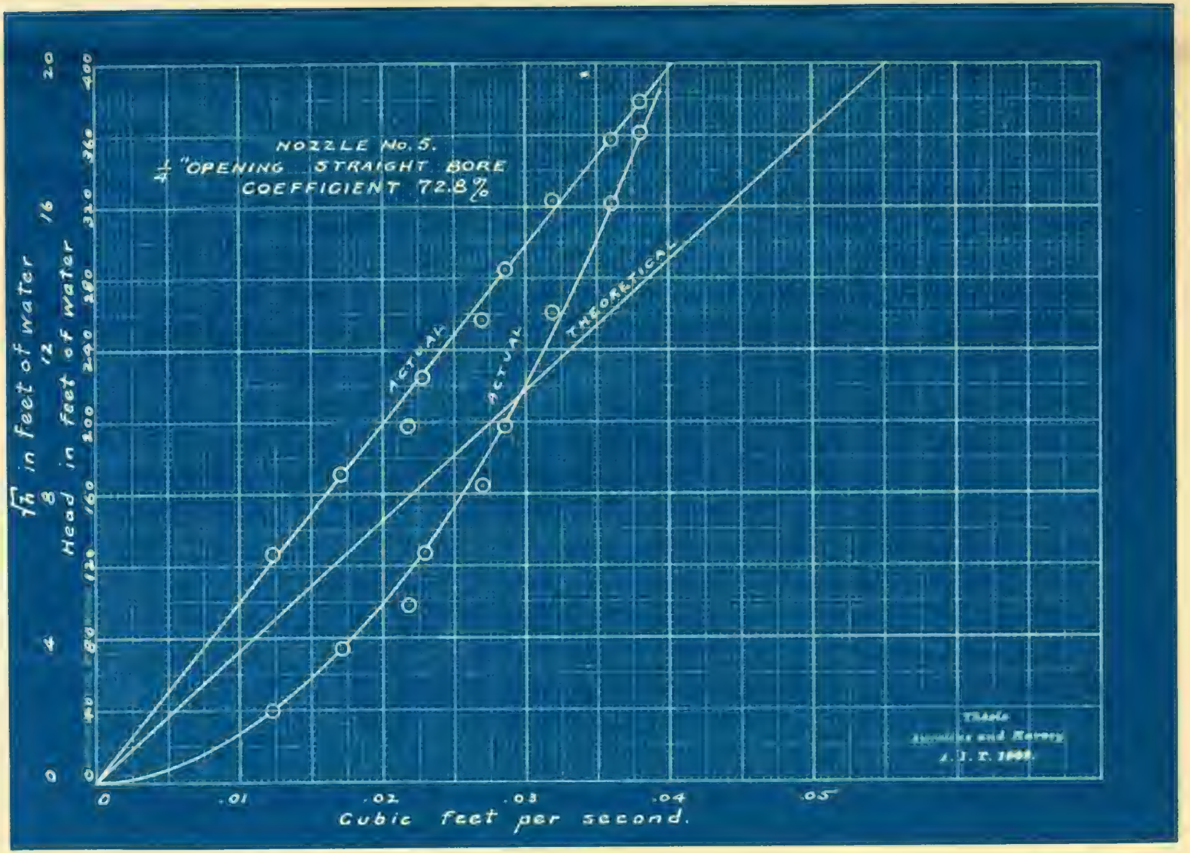
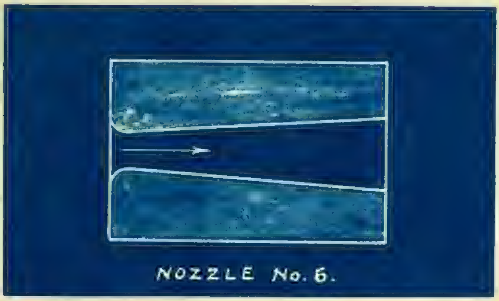

NOZZLE No. 5.
$\frac{1}{4}$" OPENING STRAIGHT BORE
COEFFICIENT 72.8%
ACTUAL
ACTUAL
THEORETICAL
$\sqrt{h}$ in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second.
0
.01
.02
.03
.04
.05
Thiele
and Harvey

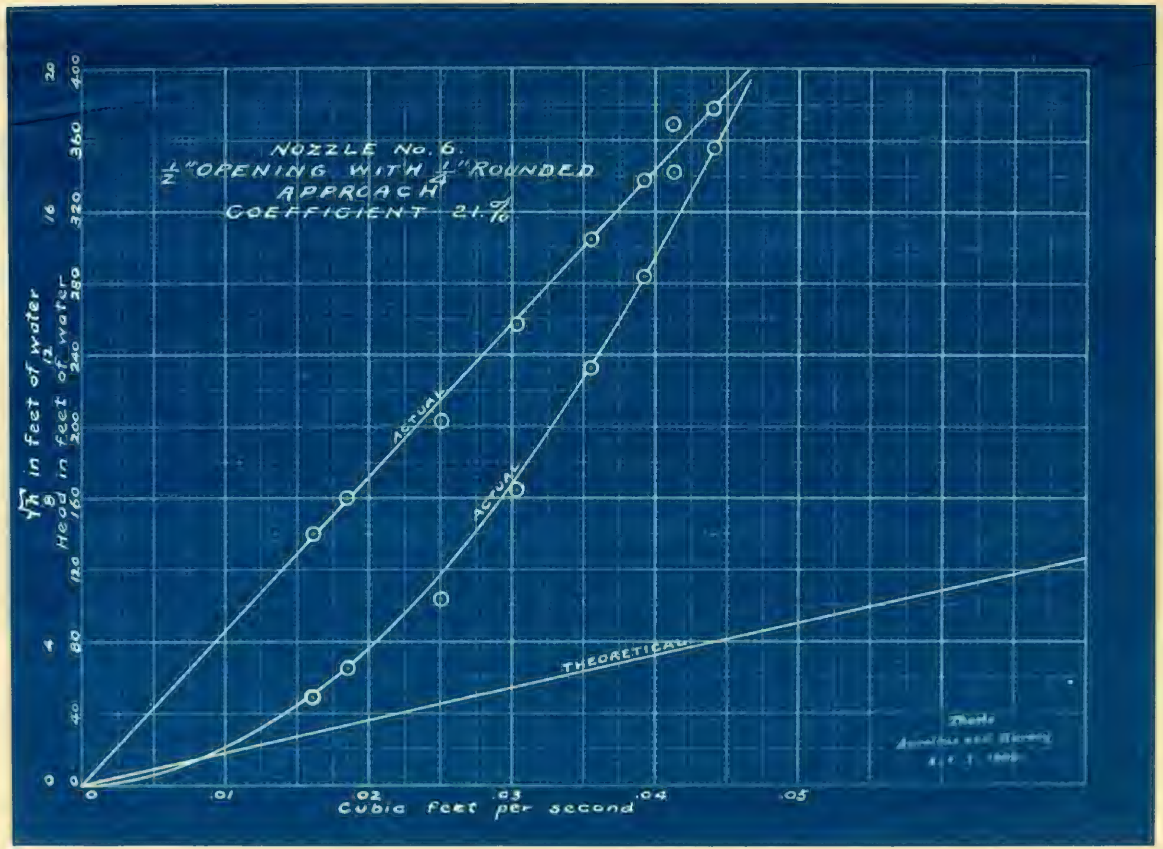
NOZZLE NO.6.

1/2" Opening with 1/4" Approach.

METER	"Hg	NOZZLE PRESSURE			DISCHARGE.
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft/Sec.
.39	.624	154	357.0	18.88	.044
.34	.583	148	342.	18.49	.0412
.31	.556	123	285.	16.89	.0393
.23	.479	101	234.	15.30	.0338
.18	.424	72	166.	12.89	.0303
.12	.346	45	104.	10.19	.0350
.05	.235	28	64.6	8.04	.0168
.03	.173	21	49.7	7.04	.0124



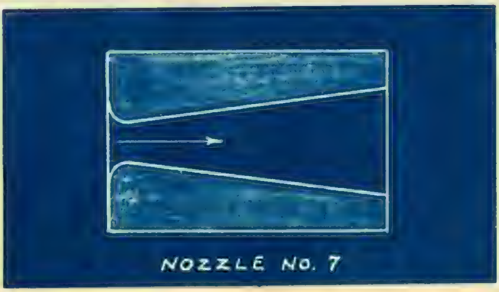
NOZZLE No. 6.

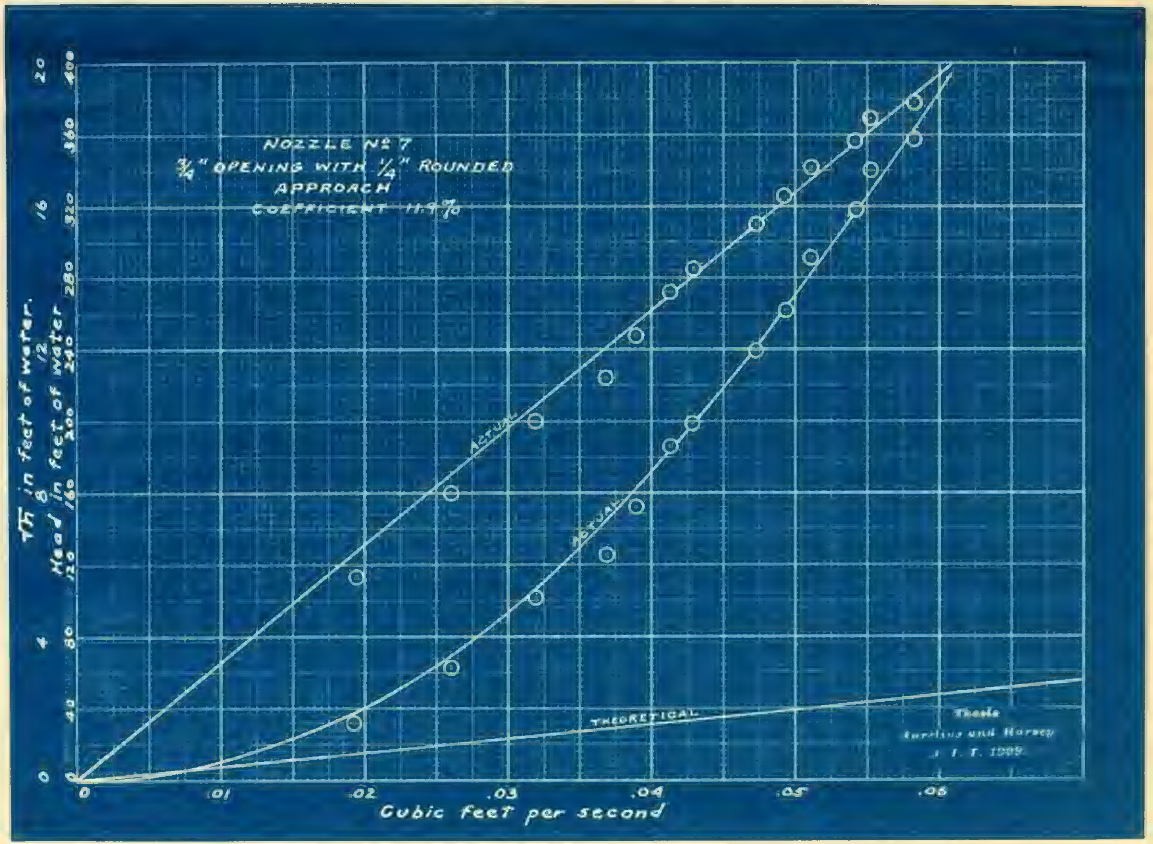

NOZZLE No. 6.
½" OPENING WITH ¼" ROUNDED
APPROACH
COEFFICIENT 21.%
ACTUAL
ACTUAL
THEORETICAL
$\sqrt{h}$ in feet of water
Head in feet of water
0
4
8
12
16
20
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second
0
.01
.02
.03
.04
.05

NOZZLE NO.7

3/4" Opening with 1/4" Rounded Approach

Meter	"Hg	NOZZLE PRESSURE			DISCHARGE.
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft./Sec
.70	.8365	155.5	358.0	18.92	.0584
.63	.7940	148.	341.	18.47	.0552
.60	.7746	138.	319.	17.83	.0542
.53	.7276	127.	292.	17.12	.0511
.49	.70	113.5	262.	16.35	.0492
.45	.6715	102.5	242.	15.56	.0484
.37	.6080	89.	205.	14.33	.0428
.34	.583	81.	187.	13.67	.0413
.30	.5476	67.	154.	12.43	.0387
.27	.5198	55	127.	11.26	.0367
.20	.4474	43.5	103.	10.08	.0318
.13	.3605	28.	64.5	8.03	.0260
.07	.2646	14.5	33.5	5.78	.0193



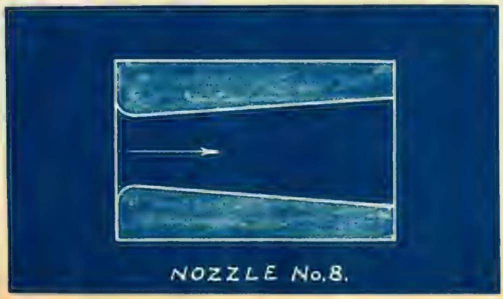

NOZZLE Nº 7
¾" OPENING WITH ¼" ROUNDED
APPROACH
COEFFICIENT 11.9%
ACTUAL
ACTUAL
THEORETICAL
$\sqrt{h}$ in feet of water.
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second
0
.01
.02
.03
.04
.05
.06
Thesis
[illegible] and Harvey
A. I. T. 1909

[illegible]
[illegible] INSTITUTE OF [illegible]
[illegible]

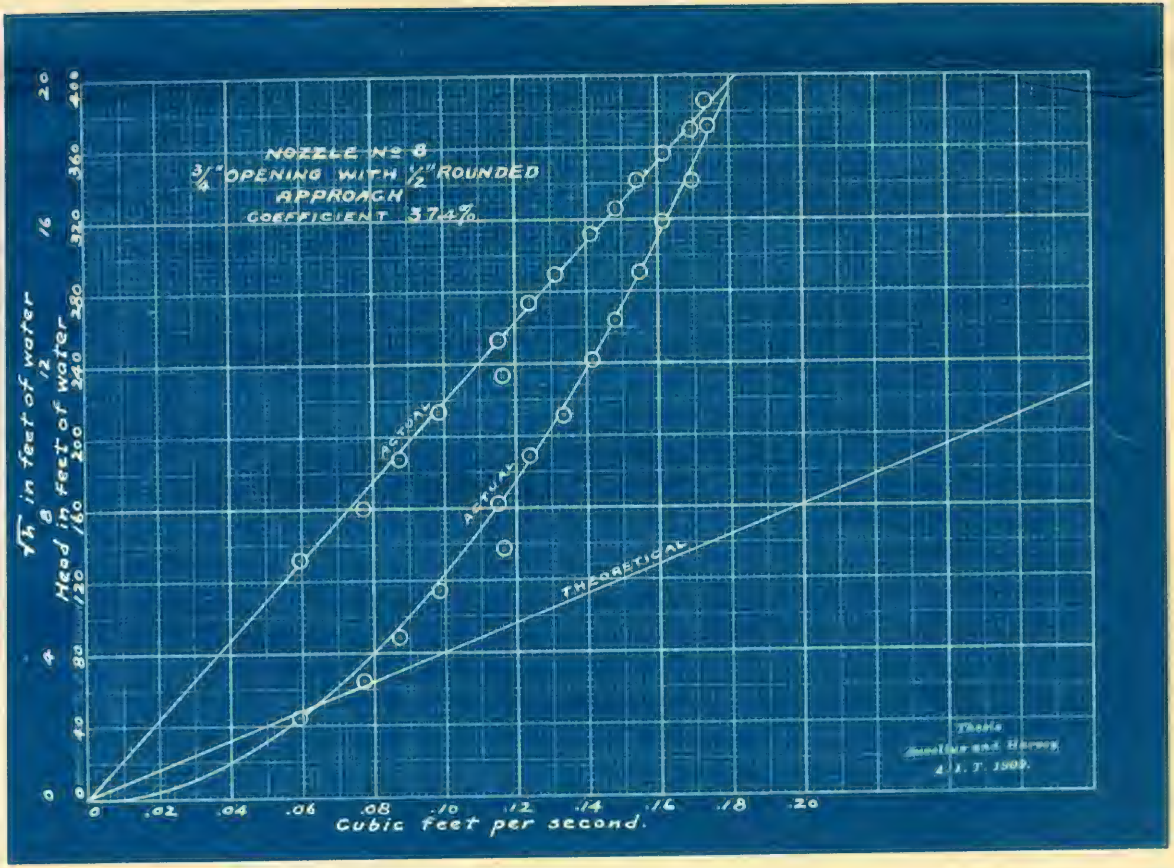
NOZZLE NO.8.

3/4"Opening with 1/2" Rounded approach

Meter	"Hg	NOZZLE PRESSURE		DISCHARGE.	
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft/Sec
6.25	2.498	161	371	19.26	.1727
5.76	2.40	148	341	18.47	.1692
5.46	2.334	138	319	17.83	.1615
5.00	2.235	127	292	17.12	.1545
4.60	2.146	115	265	16.28	.1483
4.04	2.05	102	242	15.56	.1417
3.62	1.903	92	212	14.56	.1317
3.21	1.792	82	189	13.75	.1238
2.76	1:662	70	163	12.76	.1152
2.37	1.538	60	138	11.76	.1165
2.00	1.414	50	115	10.73	.0981
1.56	1.249	38	88	9.42	.0867
1.21	1.10	28	64	8.03	.0765
.72	.848	19	44	6.62	.0593



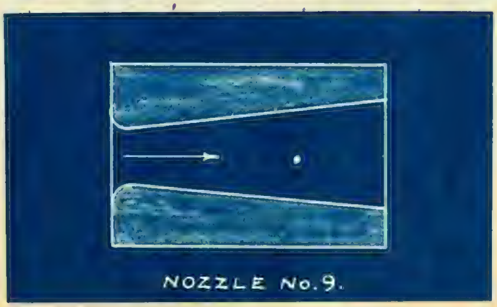
NOZZLE No.8.


NOZZLE No 8
3/4" OPENING WITH 1/2" ROUNDED
APPROACH
COEFFICIENT 374%
ACTUAL
ACTUAL
THEORETICAL
√h in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second.
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
Thesis
A. I. T. 1909.

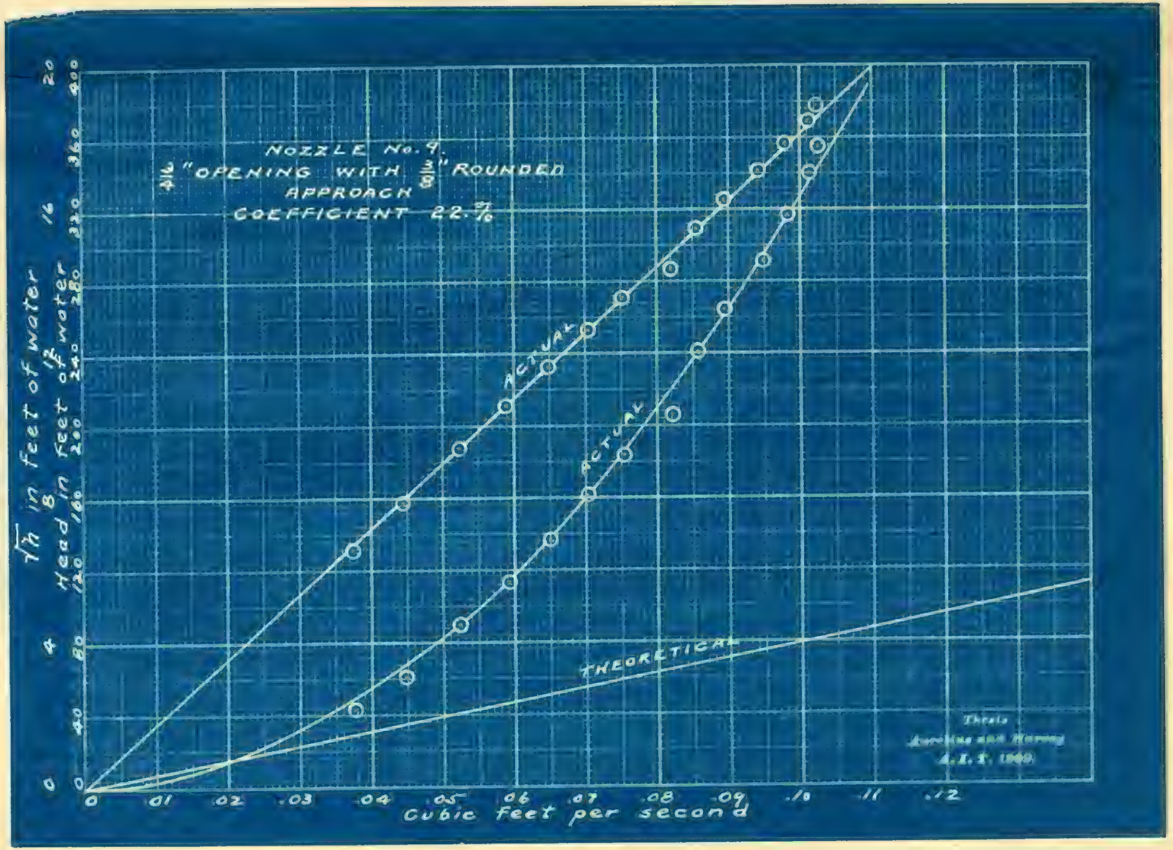
NOZZLE NO. 9.

3/4" Opening with 3/2" Rounded Approach

Meter	"Hg	NOZZLE PRESSURE			DISCHARGE
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft./Sec.
2.17	1.473	154.5	357.0	18.87	.1022
2.11	1.452	148.	341.	18.47	.1008
1.98	1.408	138.	319.	17.83	.0978
1.84	1.356	127.	292.	17.12	.0942
1.63	1.277	115.	265.	16.28	.0886
1.52	1.233	102.5	242.	15.56	.0856
1.39	1.179	89.	205.	14.33	.0820
1.15	1.072	80.	184.	13.58	.0748
1.02	1.010	70.5	163.	12.76	.0705
.87	.932	60.	138.	11.76	.0652
.71	.842	49.	113.	10.63	.0590
.55	.741	38.5	88.8	9.42	.0522
.40	.632	26.5	61.2	7.82	.0447
.28	.528	19.	43.8	6.62	.0373



NOZZLE No. 9.


NOZZLE No. 9.
3/4" OPENING WITH 3/8" ROUNDED
APPROACH
COEFFICIENT 22.%
ACTUAL
ACTUAL
THEORETICAL
$\sqrt{h}$ in feet of water
Head in feet of water
0
4
8
12
16
20
0
40
80
120
160
200
240
280
320
360
400
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
Cubic feet per second
Thesis
A.I.T. 1909

[illegible]
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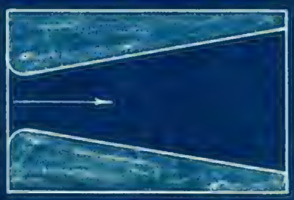
[illegible]

NOZZLE NO. IO.

1" Opening with 3/8" Rounded Approach

Meter	"Hg	NOZZLE PRESSURE			DISCHARGE.
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft./Sec.
2.30	1.516	156.0	360.0	18.98	.1051
2.18	1.477	148.	342.	18.49	.1025
1.99	1.410	138.	318.	17.85	.0990
1.84	1.355	126.	291.	17.05	.0943
1.67	1.292	115.	266.	16.30	.0895
1.46	1.208	101.5	234.	15.30	.0840
1.23	1.109	91.	210 .	14.50	.0772
1.19	1.09	80.	184.	13.59	.0703
1.00	1.00	68.5	158.	12.57	.0698
.85	.921	57.5	133.	11.52	.0644
.72	.847	48.	110.	10.52	.0593
.55	.742	38	87.8	9.37	.0522
.41	.640	27.	62.3	7.89	.0452
.27	.519	18.5	42.7	6.53	.0368



NOZZLE No.10.

ARMOUR
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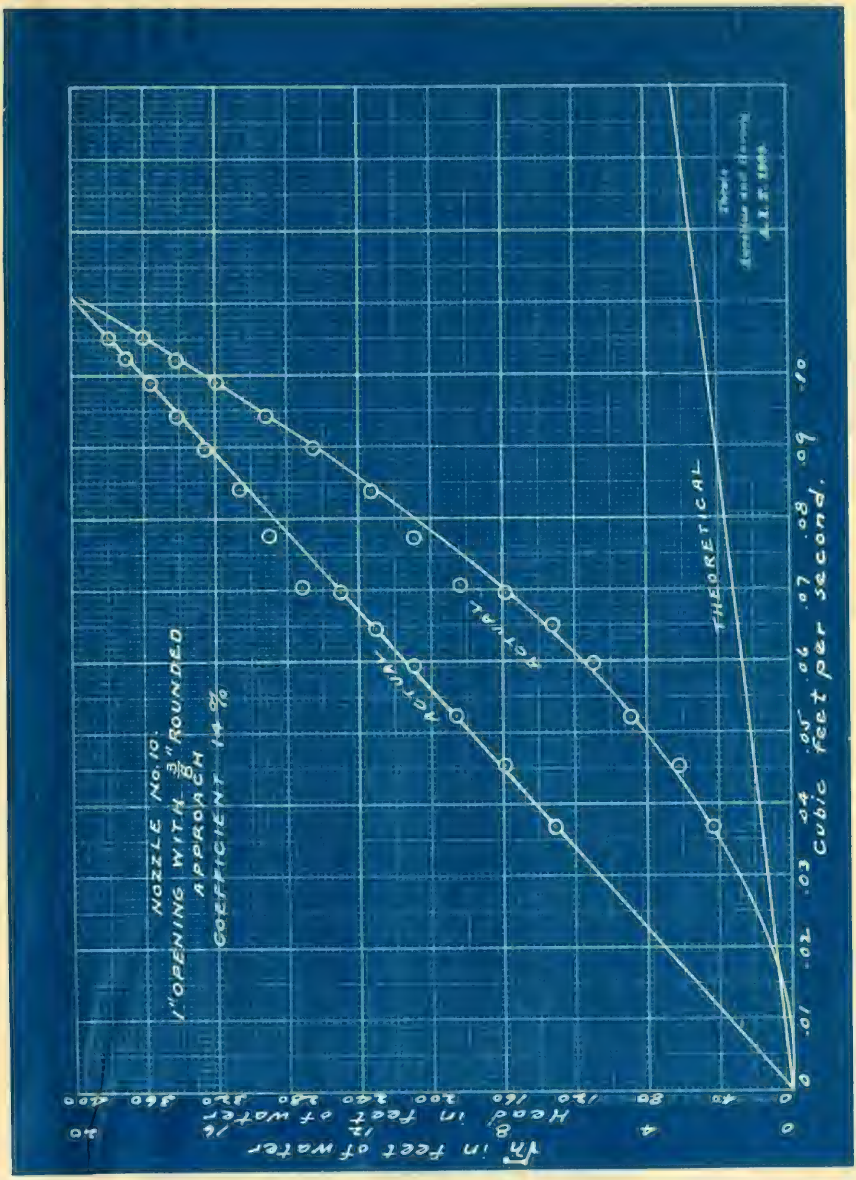
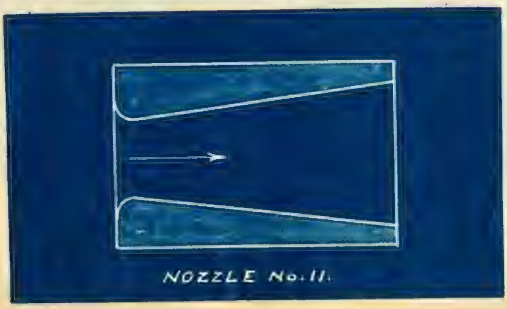

NOZZLE No. 10.
1" OPENING WITH $\frac{3}{8}$" ROUNDED
APPROACH
COEFFICIENT 14 %
ACTUAL
ACTUAL
THEORETICAL
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
Cubic feet per second.
0
40
80
120
160
200
240
280
320
360
400
Head in feet of water
0
4
8
12
16
20
$\sqrt{h}$ in feet of water

[illegible]
[illegible]
[illegible]

NOZZLE NO.11

1" Opening with 1/2" Rounded Approach

Meter	"Hg	NOZZLE PRESSURE		DISCHARGE.	
h	$\sqrt{h}$	#/sq.in.	Ft H_2O	$\sqrt{h}$	Cu.ft/Sec.
6.23	2.490	158.0	365:0	19.10	.1720
5.79	2.41	148.	342.	18.48	.1665
5.45	2.33	138.5	320.	17.88	.1611
5.07	2.248	127.	283.	17.11	.1553
4.60	2.142	115.	265.	16.28	.1481
4.09	2.02	104.	240.	15.50	.1396
3.63	1.902	92.	212.	14.56	.1315
3.21	1.79	80.	182.	13.60	.1238
2.80	1.682	69.5	160.	12.66	.1166
2.35	1.532	58.5	135.	11.62	.1062
1.96	1.398	48.	111.	10.53	.0970
1.55	1.244	38.	87.8	9.37	.0852
1.18	1.088	27.	62.3	7.89	.0758
.76	.872	18.5	42.7	6.53	.0610



NOZZLE No. 11.

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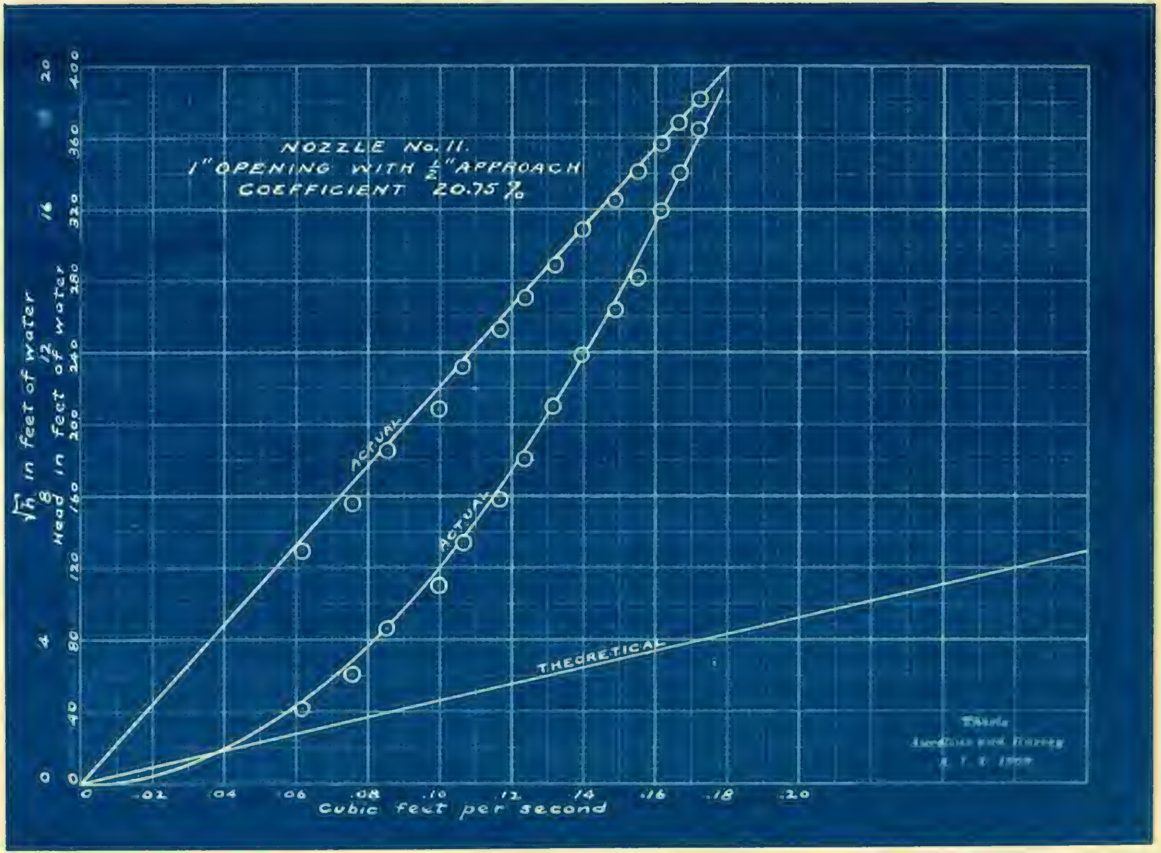
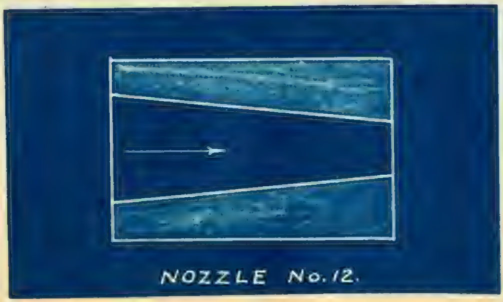

NOZZLE No. 11.
1" OPENING WITH ½" APPROACH
COEFFICIENT 20.75 %
ACTUAL
ACTUAL
THEORETICAL
$\sqrt{h}$ in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20

NOZZLE NO.12

3/8" Opening with 3/4" Approach.

Meter	"Hg	NOZZLE PRESSURE			DISCHARGE.
h	$\sqrt{h}$	#/sq:in.	Ft.H_2O	$\sqrt{h}$	Cu.ft./Sec.
2.53	1.592	155.5	358.0	18.92	.1104
2.41	1.552	148.	341.	18.47	.1076
2.22	1.488	138.	319.	17.83	.1032
2.09	1.447	127.	292.	17.12	.1004
1.90	1.378	115.	266.	16.28	.0956
1.68	1.296	102.5	242.	15.56	.0900
1.52	1.233	91.	210.	14.88	.0856
1.33	1.153	81.	187.	13.67	.0803
1.17	1.082	70.5	163.	12.76	.0755
.99	.995	60.	138.	11.76	.0693
.81	.900	49.	113.	10.63	.0629
.65	.806	38.5	88.8	9.42	.0565
.47	.685	28.	64.5	8.03	.0483
.36	.600	19.	43.8	6.62	.0423



NOZZLE No. 12.

ARMOUR
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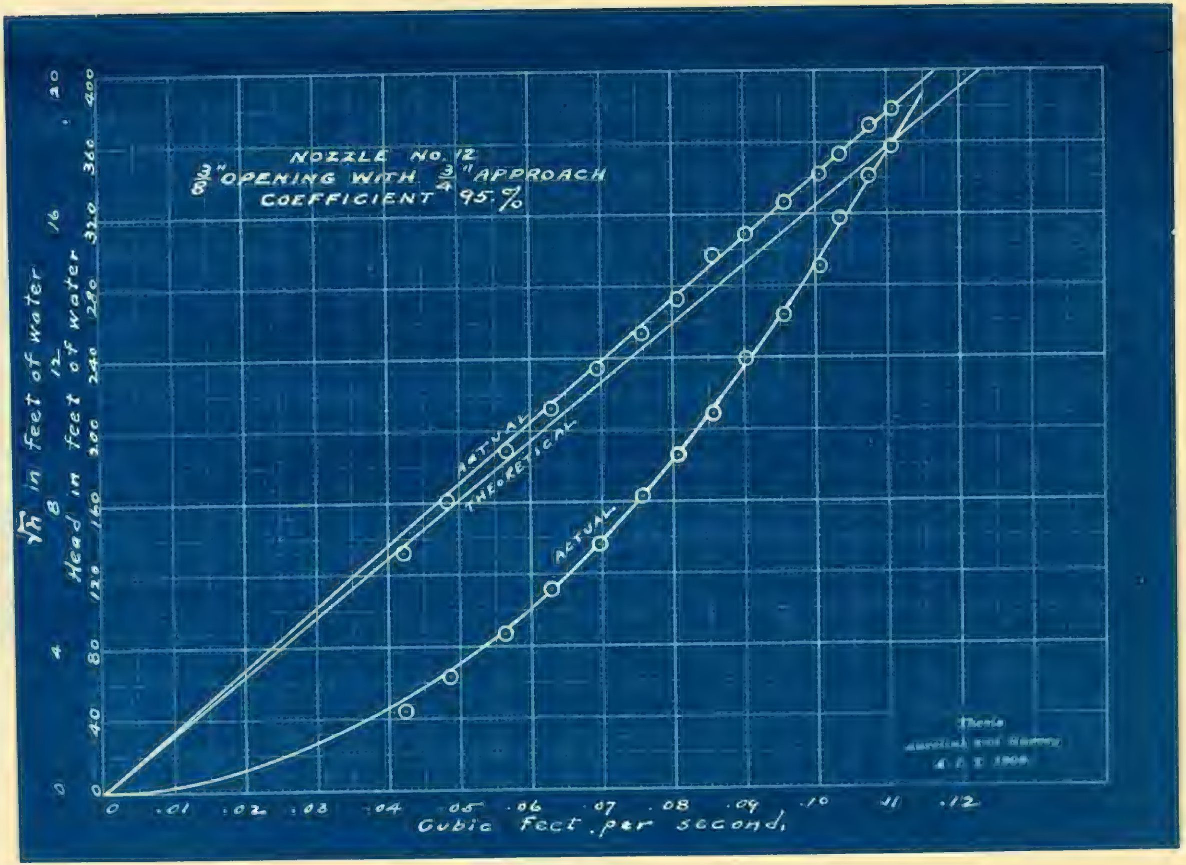
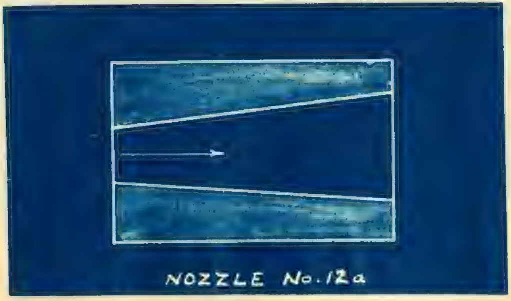

NOZZLE NO. 12
$\frac{3}{8}$" OPENING WITH $\frac{3}{4}$" APPROACH
COEFFICIENT 95 %
ACTUAL
THEORETICAL
ACTUAL
$\sqrt{h}$ in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
Cubic feet per second.
Thesis

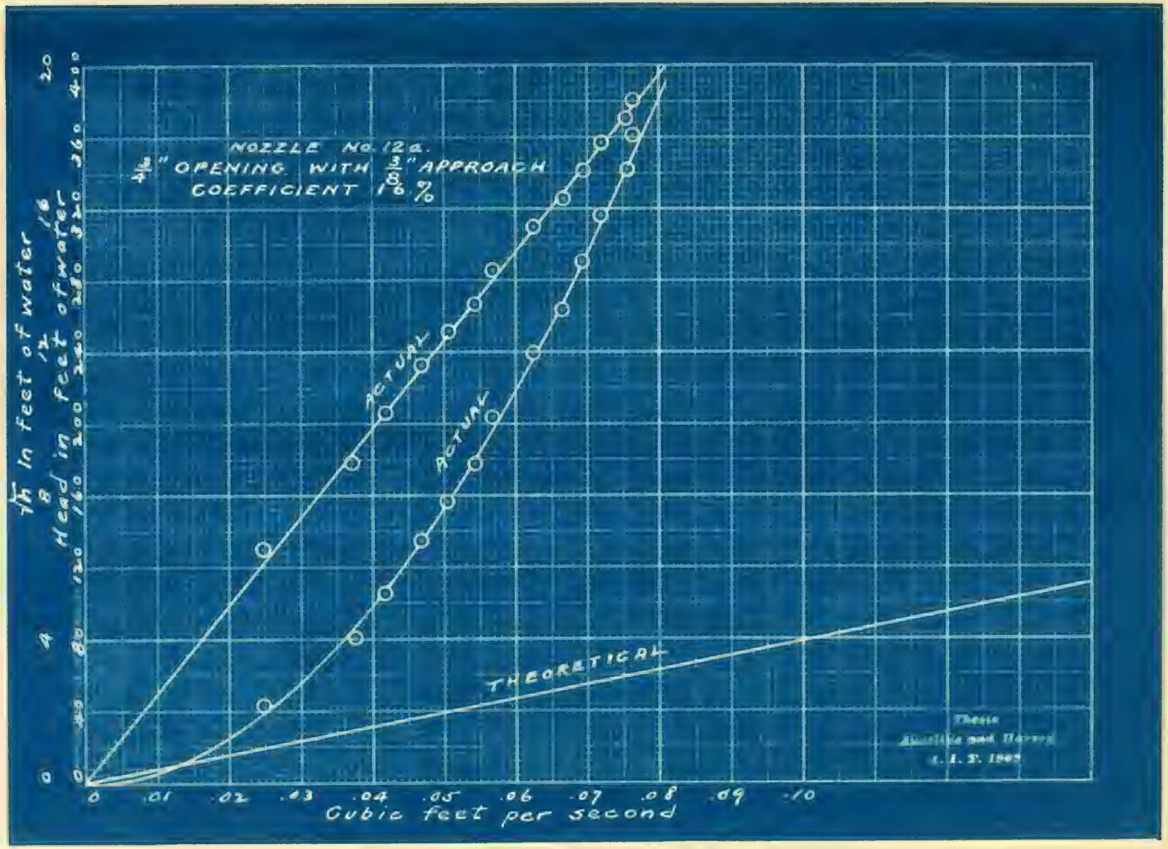
NOZZLE NO.12 (a)

3/4" Opening with 3/8" Approach

Meter	"Hg	NOZZLE PRESSURE		DISCHARGE.	
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft/Sec.
1.20	1.095	157.0	362.0	19.03	.0762
1.16	1.078	148.	342.	18.48	.0751
1.06	1.029	138.	318.	17.84	.0717
.99	.994	126.	291.	17.05	.0693
.91	.954	115.	265.	16.28	.0667
.80	.893	104.	240.	15.50	.0623
.66	.812	88.5	204.	14.30	.0568
.53	.775	77.5	178.	13.37	.0543
.44	.664	58.5	135.	11.62	.0468
.35	.592	46.	106.	10.30	.0418
.28	.529	35.	80.8	8.98	.0373
.12	.346	18.5	42.7	6.53	.0250



NOZZLE No.12a


NOZZLE No. 12a.
$\frac{3}{4}$" OPENING WITH $\frac{3}{8}$" APPROACH
COEFFICIENT 16 %
ACTUAL
ACTUAL
THEORETICAL
$\sqrt{h}$ in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
Cubic feet per second
Thesis
[illegible] and Harvey
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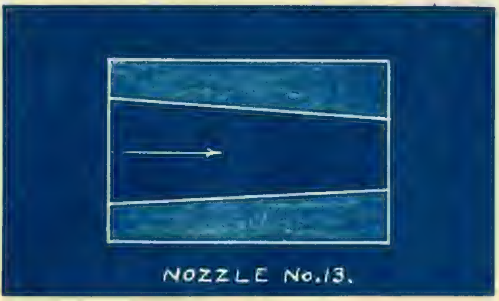
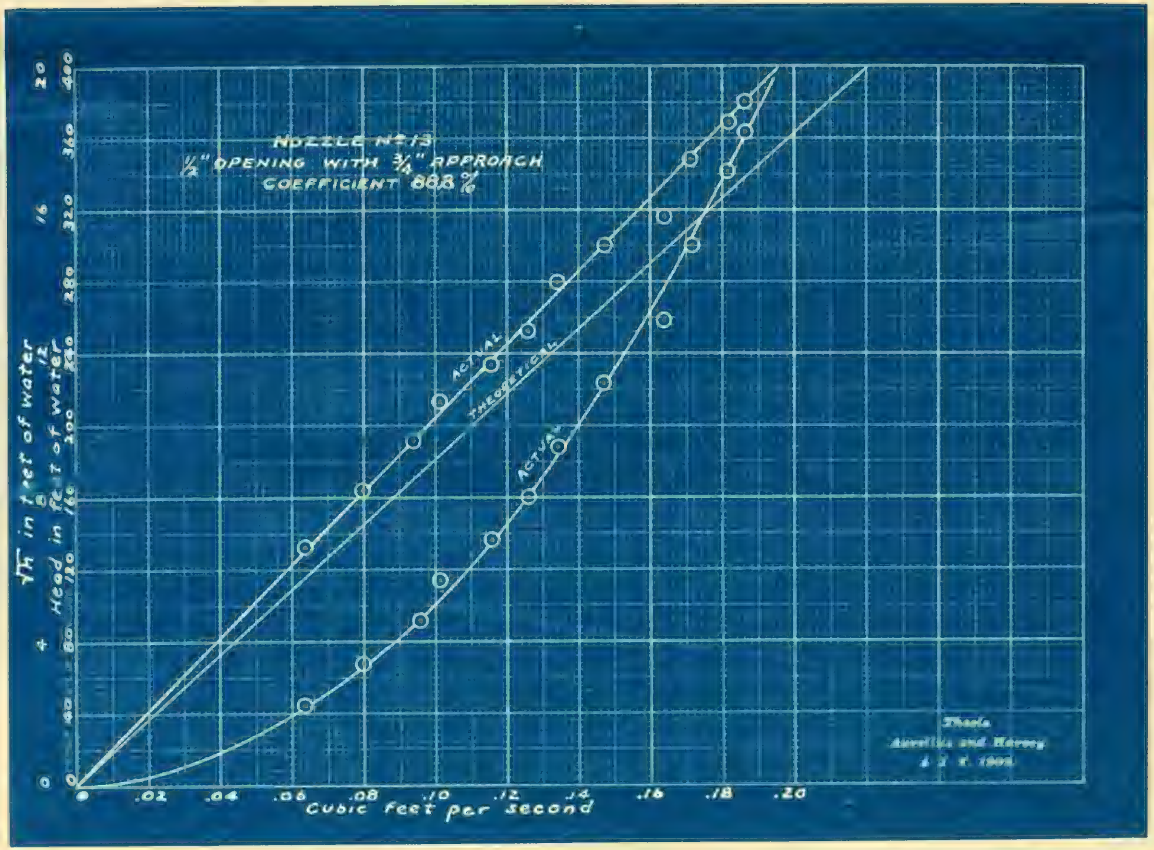
NOZZLE NO.13

1/2" Opening with 3/4" Approach

Meter	"Hg	NOZZLE PRESSURE		DISCHARGE	
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft./Sec.
7.28	2.694	157.5	363.6	19.04	.1860
6.90	2.624	148.	341.7	18.46	.1815
6.10	2.468	132.	304.7	17.43	.1705
5.60	2.364	108.	249.	15.78	.1635
4.50	2.120	97.5	225.	15.00	.1465
3.75	1.935	82.	189.3	14.08	.1338
3.30	1.815	70.	161.2	12.69	.1255
2.79	1.670	60.	138.5	11.75	.1155
2.25	1.500	50.	115.	10.73	.1040
1.80	1.341	40.	92.4	9.61	.0932
1.30	1.139	29.5	68.1	8.25	.0792
.83	.911	19.5	45.0	6.70	.0637



NOZZLE No.13.



NOZZLE Nº 13
½" OPENING WITH ¾" APPROACH
COEFFICIENT 88.8 %
ACTUAL
THEORETICAL
ACTUAL
√h in feet of water
Head in feet of water
0
4
8
12
16
20
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
Thesis

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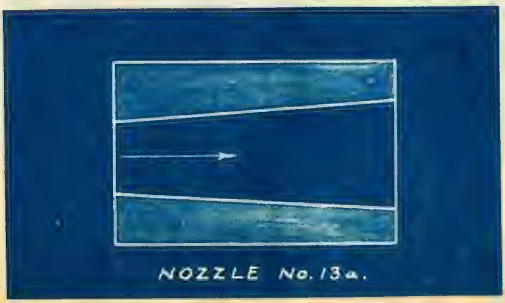
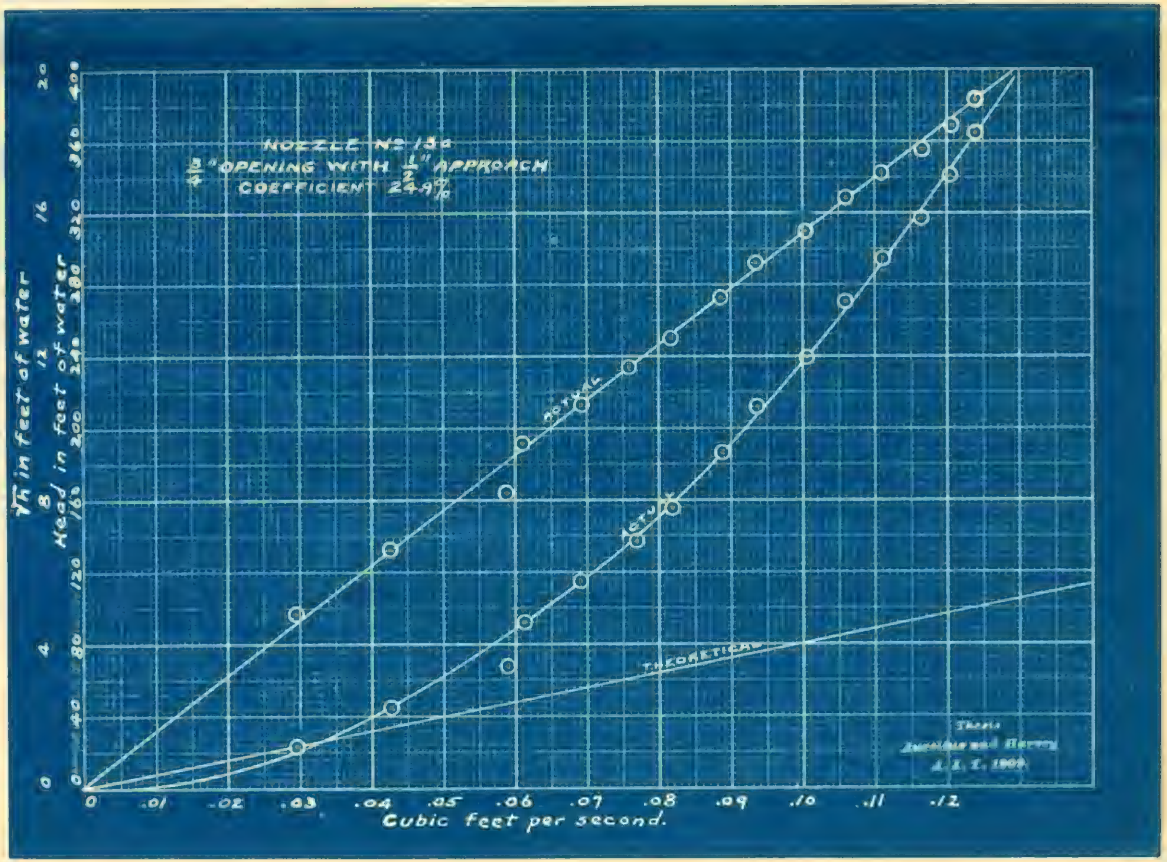
NOZZLE NO. 13(a)

3/4" Opening with 1/2" Approach

Meter	"Hg	NOZZLE PRESSURE		DISCHARGE.	
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft./Sec
3.22	1.793	158.0	365.0	19.10	.1241
3.05	1.745	148.	342.	18.46	.1207
2.84	1.684	137.	316.2	17.74	.1166
2.57	1.602	128.	295.	17.18	.1111
2.34	1.528	117.5	271.	16.45	.1060
2.20	1.482	104.	240.	15.50	.1028
1.82	1.347	92.5	213.5	14.63	.0935
1.63	1.275	81.	187.	13.66	.0886
1.38	1.174	67.5	156.	12.47	.0816
1.20	1.090	60.	138.5	11.75	.0758
.98	.990	50.	115.5	10.73	.0690
.76	.871	40.	92.4	9.61	.0609
.54	.734	29.5	68.1	8.25	.0584
.36	.600	19.5	45.	6.7	.0425
.17	.412	10.	23.	4.88	.0294



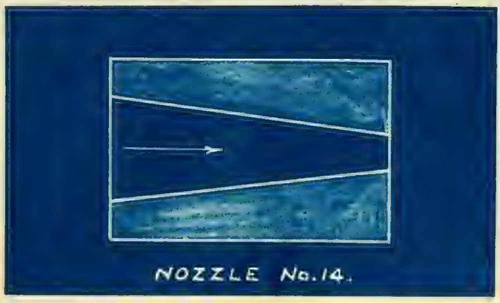
NOZZLE No. 13a.


NOZZLE Nº 13a
$\frac{3}{4}$" OPENING WITH $\frac{1}{2}$" APPROACH
COEFFICIENT 24.9%
ACTUAL
ACTUAL
THEORETICAL
√h in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
Cubic feet per second.
Thesis
[illegible] and Harvey
A. I. T. 1909

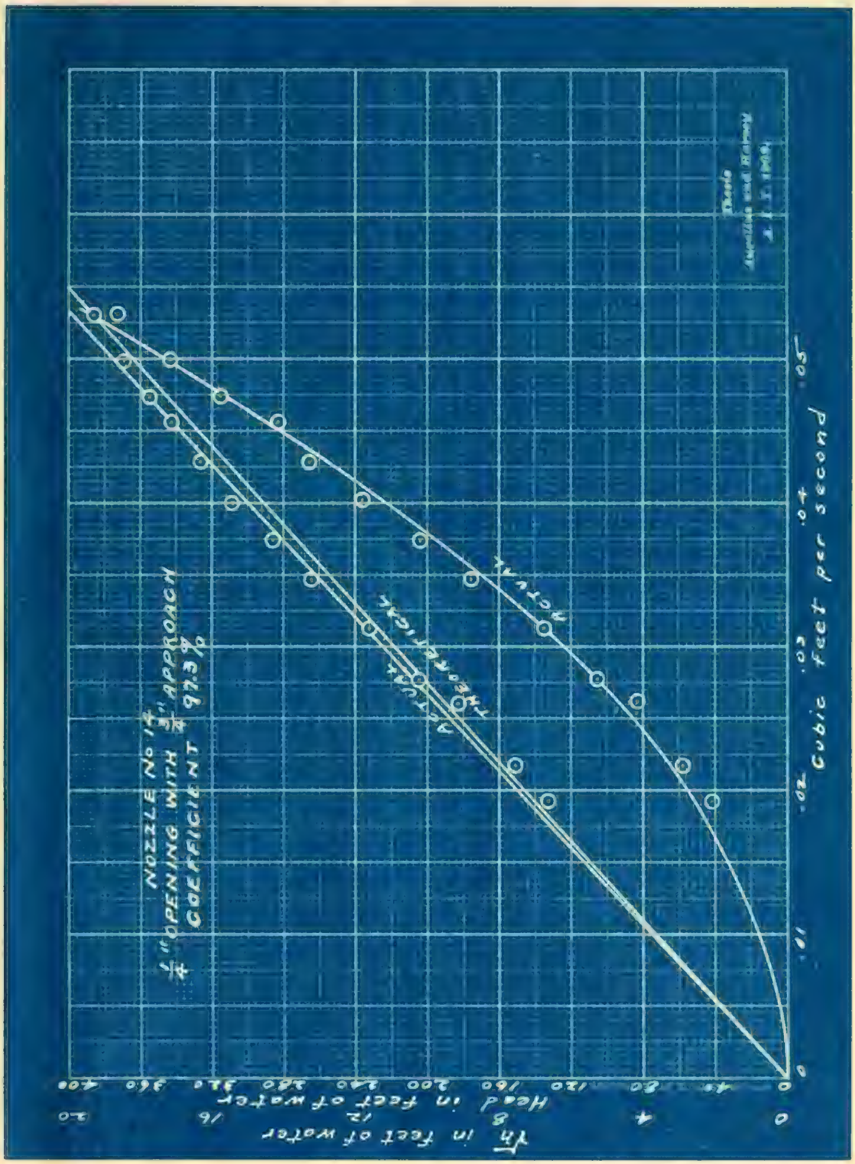
NOZZLE NO.14.

1/4" Opening with 3/4" Approach

Meter	Hg.	Nozzle Pressure			Discharge.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft./Sec
.57	.755	160.5	372.	19.27	.0530
.50	.707	148.	342.	18.48	.0498
.45	.671	136.5	315.	17.74	.0473
.42	.648	127.	283.	17.11	.0456
.37	.608	115.	265.	16.28	.0428
.32	.565	103.	237.	15.41	.0400
.28	.528	88.5	204.	14.30	.0373
.24	.489	76.5	176.	13.28	.0346
.19	.436	58.5	135.	11.62	.0312
.15	.387	46.	106.	10.30	.0377
.13	.361	36.	83.	9.12	.0260
.09	.300	25.	57.	7.60	.0217
.07	.264	19.	44.	6.62	.0192



NOZZLE No.14.


NOZZLE No 14
$\frac{1}{4}$" OPENING WITH $\frac{3}{4}$" APPROACH
COEFFICIENT 97.3%
ACTUAL
THEORETICAL
ACTUAL
Cubic feet per second
0
.01
.02
.03
.04
.05
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
$\sqrt{h}$ in feet of water
0
4
8
12
16
20

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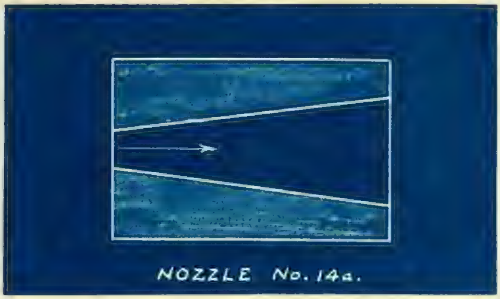
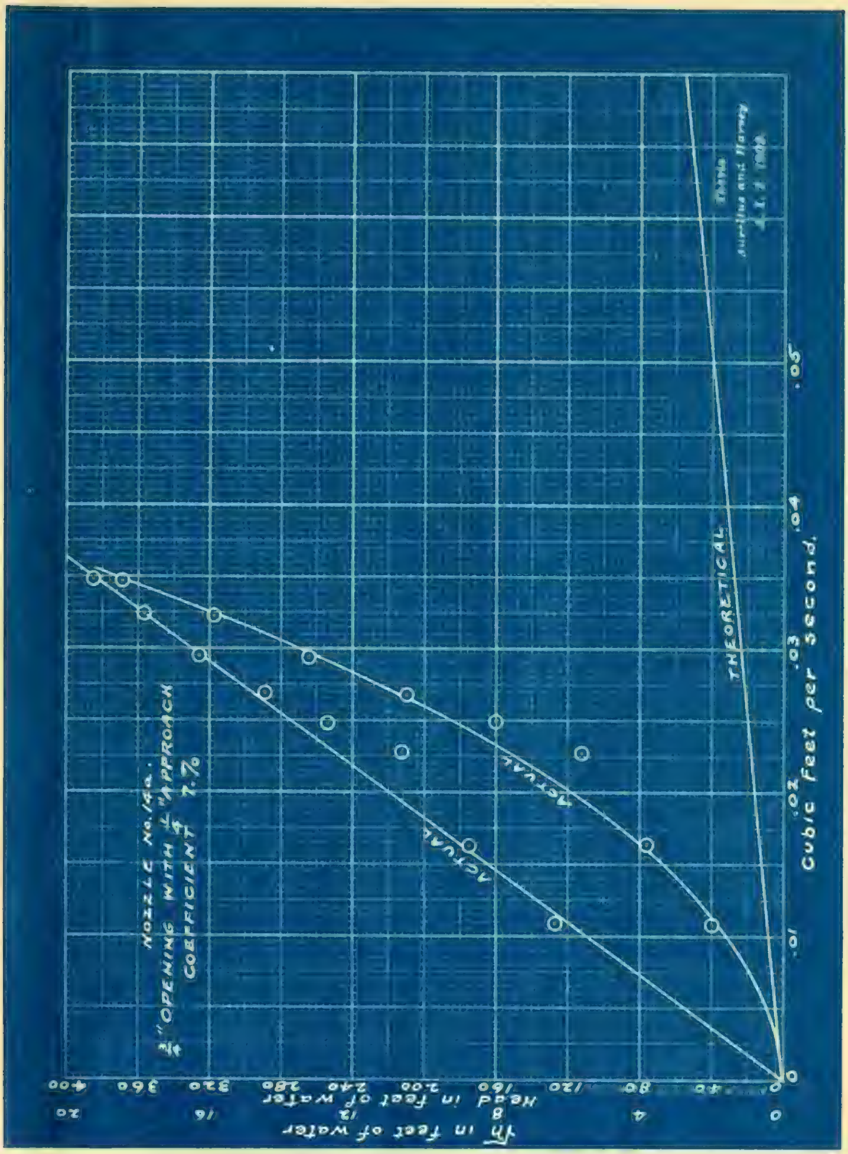
NOZZLE NO.14 (a)

3/4"Opening with 1/8" Approach.

Meter	Hg.	Nozzle Pressure			Discharge.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft./Sec
.24	.489	160.0	369.0	19.22	.0347
.21	.458	138.	318.	17.84	.0323
.17	.412	115.	265.	16.28	.0294
.14	.374	91.	210.	14.49	.0268
.12	.346	69.5	160.	12.66	.0248
.10	.316	49.	113.	10.62	.0227
.05	.223	32.8	75.8	8.70	.0164
.02	.141	17.5	40.4	6.35	.0108



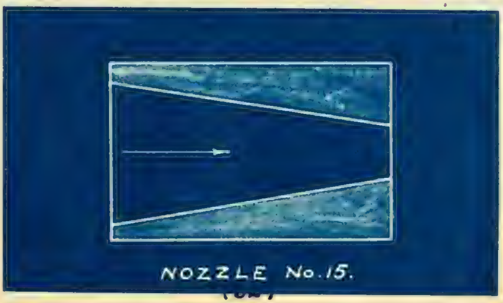
NOZZLE No. 14a.


NOZZLE No. 14a.
3/4" OPENING WITH 1/4" APPROACH
COEFFICIENT 7.7%
ACTUAL
ACTUAL
THEORETICAL
Cubic Feet per Second.
0
.01
.02
.03
.04
.05
√h in feet of water
0
4
8
12
16
20
Head in feet of water
0
.40
.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
Thesis

NOZZLE NO. 15.

3/8" Opening with 1" Approach

Meter Hg		Nozzle Pressure		Discharge	
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft./Sec.
1.98	1.405	157.0	362.0	19.03	.0975
1.80	1.340	148.	342.	18.48	.0916
1.68	1.295	138.	318.	17.48	.0898
1.55	1.244	126.	291.	17.05	.0850
1.40	1.182	115.	265.	16.28	.0842
1.23	1.109	101.5	237.	15.42	.0772
1.14	1.068	88.5	204.	14.30	.0703
.99	.994	78.5	181.	13.47	.0693
.85	.922	69.5	160.	12.66	.0643
.74	.859	58.5	135.	11.62	.0600
.61	.780	48.5	112.	10.58	.0547
.46	.678	36.	83.1	9.11	.0477
.30	.547	23.	53.1	7.28	.0387
.17	.412	15.	34.7	5.88	.0294



NOZZLE No. 15.

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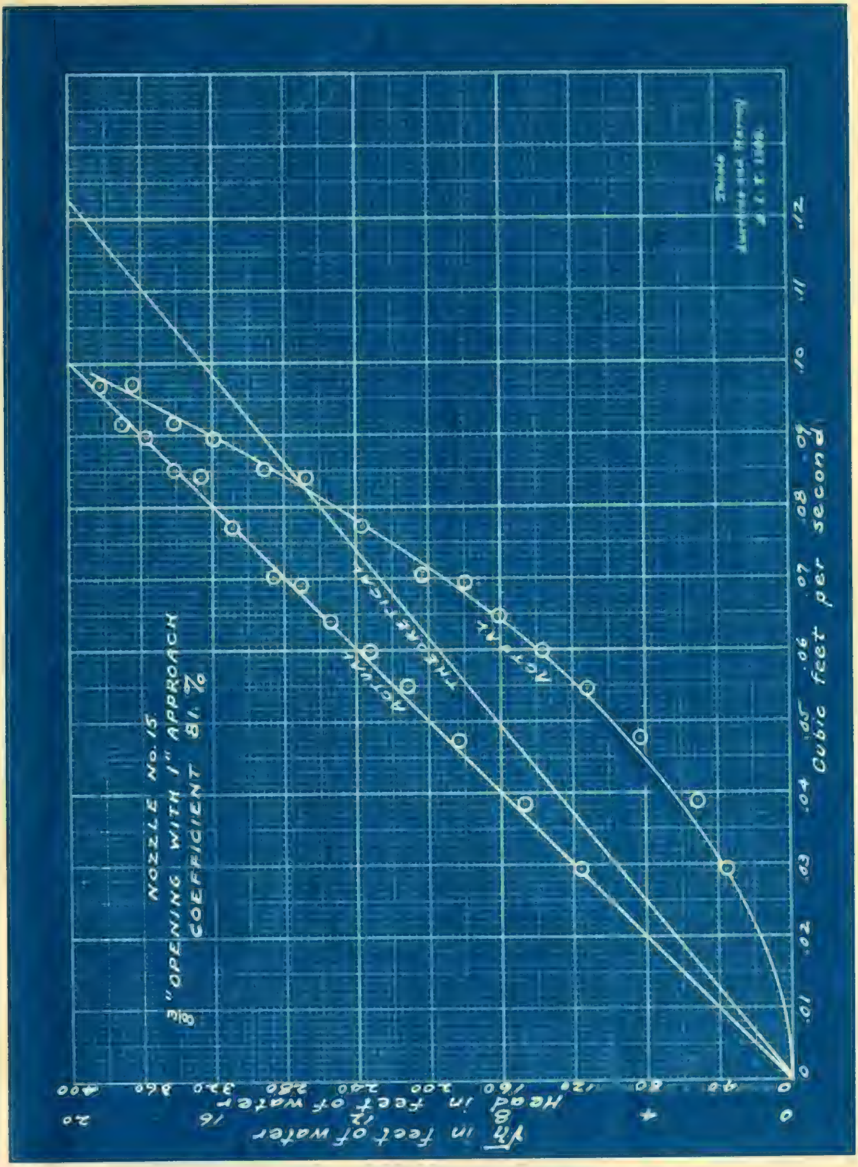
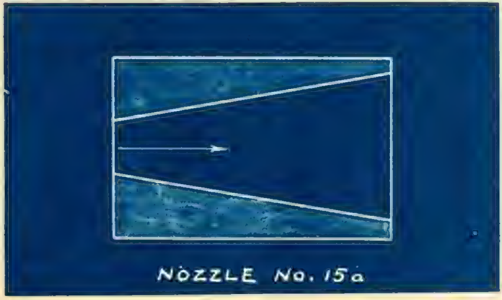
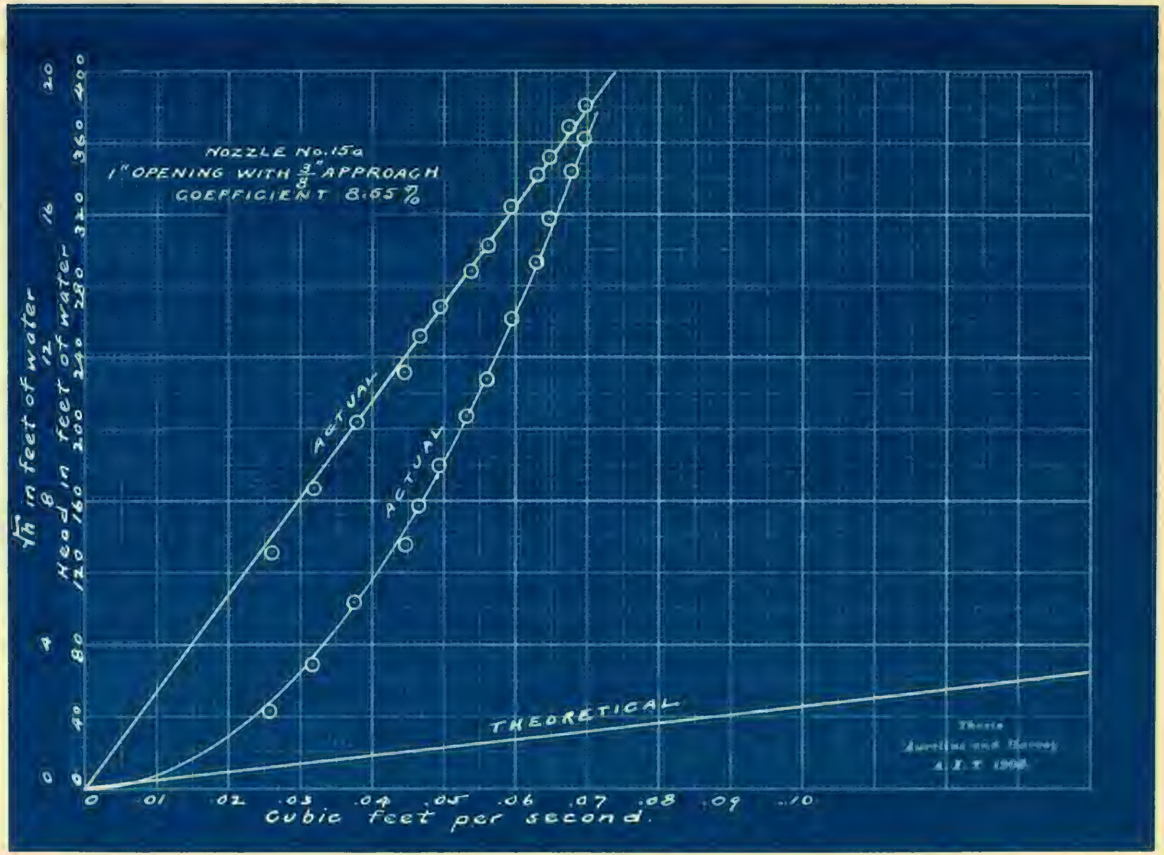

NOZZLE NO. 15
3/8 "OPENING WITH 1" APPROACH
COEFFICIENT 81.%
Actual
Theoretical
Actual
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
Cubic feet per second
0
40
80
120
160
200
240
280
320
360
400
Head in feet of water
0
4
8
12
16
20
√h in feet of water

Nozzle No.15.(a)

1" Opening with 3/8" Approach

Meter	Hg	NOZZLE PRESSURE			DISCHARGE.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft/ Sec.
1.01	1.004	157.0	362.0	19.03	.0695
.93	.963	149.	344.	18.53	.0672
.88	.937	137.	317.	18.78	.0648
.81	.900	127.	293.	17.11	.0630
.72	.848	113.5	262.	16.19	.0593
.64	.800	99.	228.	15.11	.0560
.58	.762	90.	207.	14.41	.0535
.49	.700	77.5	179.	13.38	.0492
.44	.664	68.5	158.	12.58	.0467
.40	.633	58.5	135.	11.62	.0447
.28	.529	45.	103.	10.19	.0374
.20	.447	30.	69.3	8.32	.0318
.13	.360	18.5	42.7	6.53	.0360

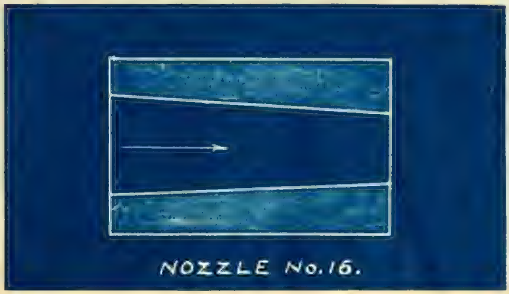

NOZZLE No. 15a


NOZZLE No. 15a
1" OPENING WITH 3/8" APPROACH
COEFFICIENT 8.65%
√h in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
ACTUAL
ACTUAL
THEORETICAL
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
Cubic feet per second.
Thesis
[illegible] and Harvey
A. I. T. 1908

NOZZLE NO. 16.

1/2" Opening with 1" Approach

Meter	Hg	NOZZLE PRESSURE			DISCHARGE.
h	$\sqrt{h}$	#/Sq.In.	Ft.H_2O	$\sqrt{h}$	Cu.ft./Sec
7.80	2.790	157.0	362.0	19.02	.1928
7.31	2.700	148.	342.	18.49	.1865
6.80	2.604	138.	318.	17.84	.1800
6.07	2.460	127.	293.	17.11	.1700
5.66	2.375	115.	266.	16.30	.1642
5.05	2.245	103.	238.	15.42	.1552
4.51	2.120	92.	212.	14.57	.1465
4.03	2.005	80.	185.	13.60	.1382
3.49	1.868	69.5	161.	12.66	.1292
2.87	1.694	57.5	133.	11.53	.1173
2.47	1.570	48.	111.	10.53	.1088
1.93	1.389	38.	87.8	9.37	.0963
1.40	1.182	27.	62.3	7.89	.0842
.87	.932	17.5	40.4	6.36	.0658



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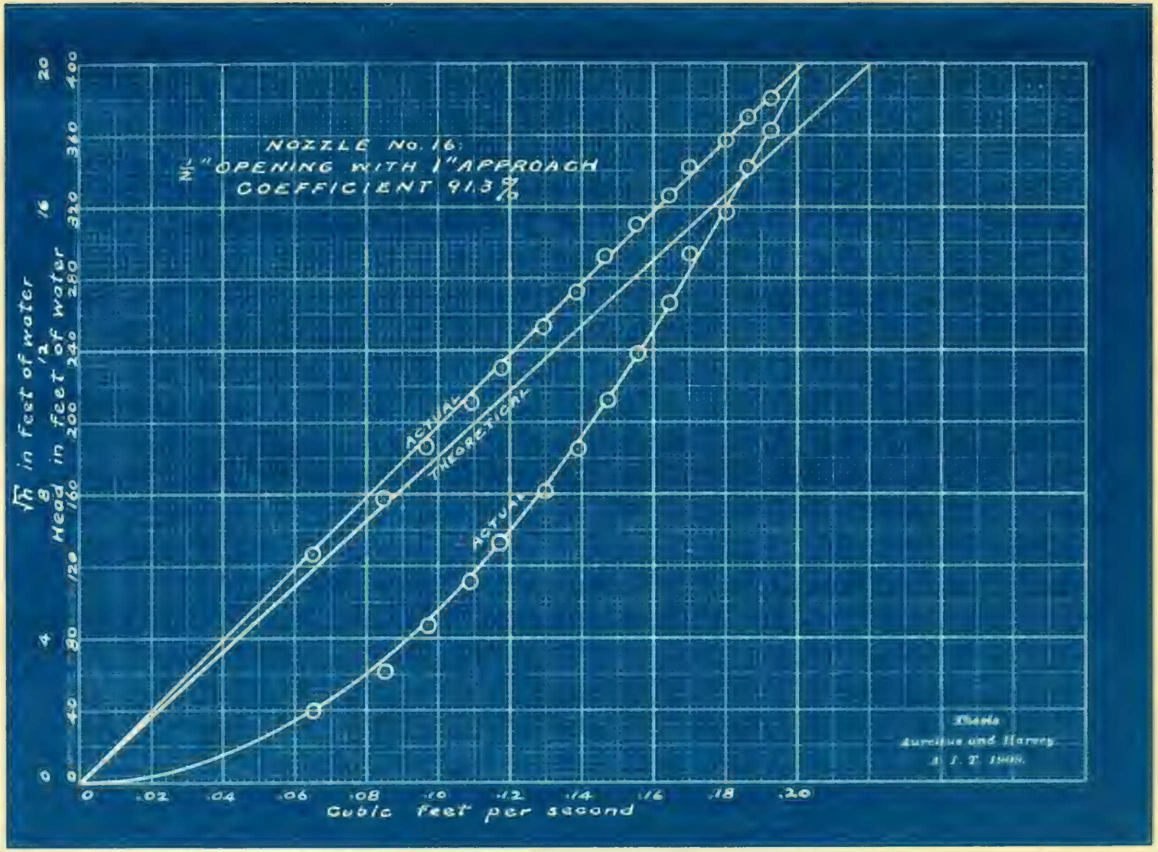
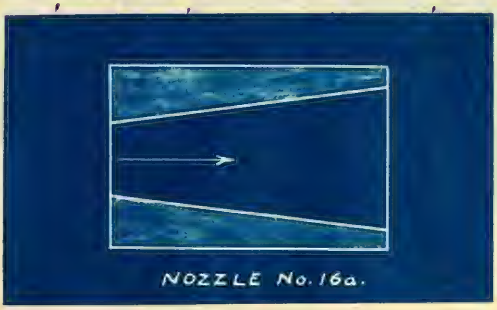

NOZZLE No. 16:
½" OPENING WITH 1" APPROACH
COEFFICIENT 91.3%
ACTUAL
THEORETICAL
ACTUAL
√h in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
Cubic feet per second
Thesis
Aurelius and Harvey
A. I. T. 1909.

NOZZLE NO.16 (a)

1" Opening with 1/2 " Approach

Meter	Hg.	NOZZLE PRESSURE			DISCHARGE.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft./Sec.
3.55	1.883	158.5	366.0	19.10	.1303
3.30	1.815	148.	342.	18.48	.1256
3.08	1.754	138.	318.	17.84	.1213
2.80	1.682	126.	291.	17.05	.1166
2.60	1 .611	115.	265	16.28	.1117
2.33	1.524	104.	240	15.5	.1057
2.06	1.435	91.	210	14.49	.0997
1.82	1.348	78.5	181	13.47	.0923
1.61	1.267	69.5	160	12.66	.0880
1.30	1.140	57.5	133	11.52	.0792
1.11	1.052	47.	108	10.41	.0733
.87	.932	38.	87.8	9.37	.0652
.60	.775	25.	57.7	7.59	.0545
.39	.624	16.5	38.1	6.17	.0440



NOZZLE No. 16a.

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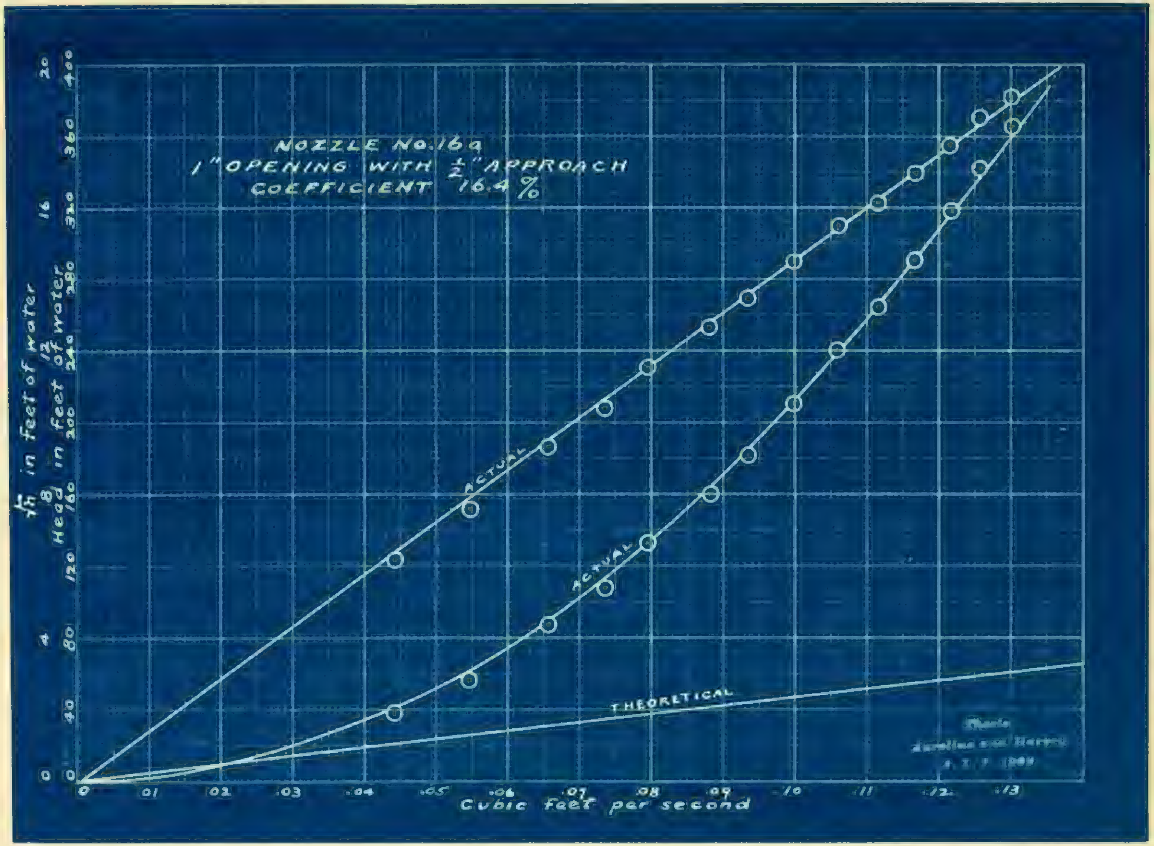
NOZZLE No.16a
1" OPENING WITH ½" APPROACH
COEFFICIENT 16.4 %
ACTUAL
ACTUAL
THEORETICAL
√h in feet of water
Head in feet of water
0
4
8
12
16
20
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13

ARMOUR
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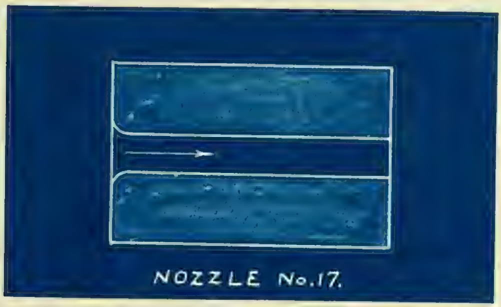
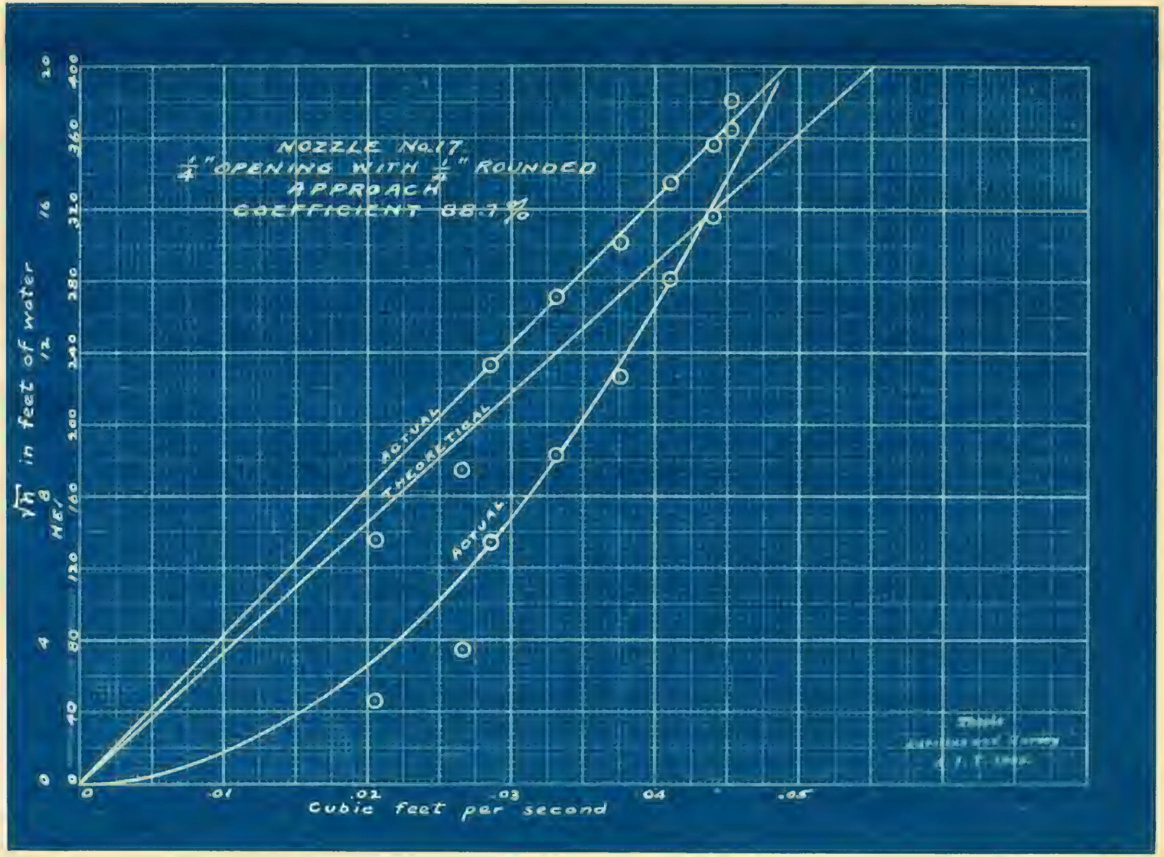
NOZZLE NO.17

1/4" Opening with 1/2" Rounded Approach

Meter	Hg	NOZZLE PRESSURE			DISCHARGE.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft./Sec
.41	.640	157	363.0	19.20	.0452
.39	.625	137	316.	17.80	.0440
.33	.575	122	282.	16.77	.0408
.28	.529	99	228.	15.10	.0375
.22	.465	80	184.	13.56	.0328
.16	.400	51	118.	11.67	.0285
.14	.374	33	76.4	8.74	.0267
.08	.283	20	46.2	6.79	.0205




NOZZLE No.17.
¼" OPENING WITH ¼" ROUNDED
APPROACH
COEFFICIENT 88.7%
ACTUAL
THEORETICAL
ACTUAL
√h in feet of water
HEAD
0
4
8
12
16
20
0
40
80
120
160
200
240
280
320
360
400
0
.01
.02
.03
.04
.05
Cubic feet per second

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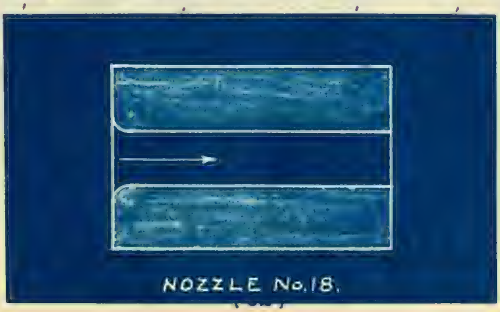
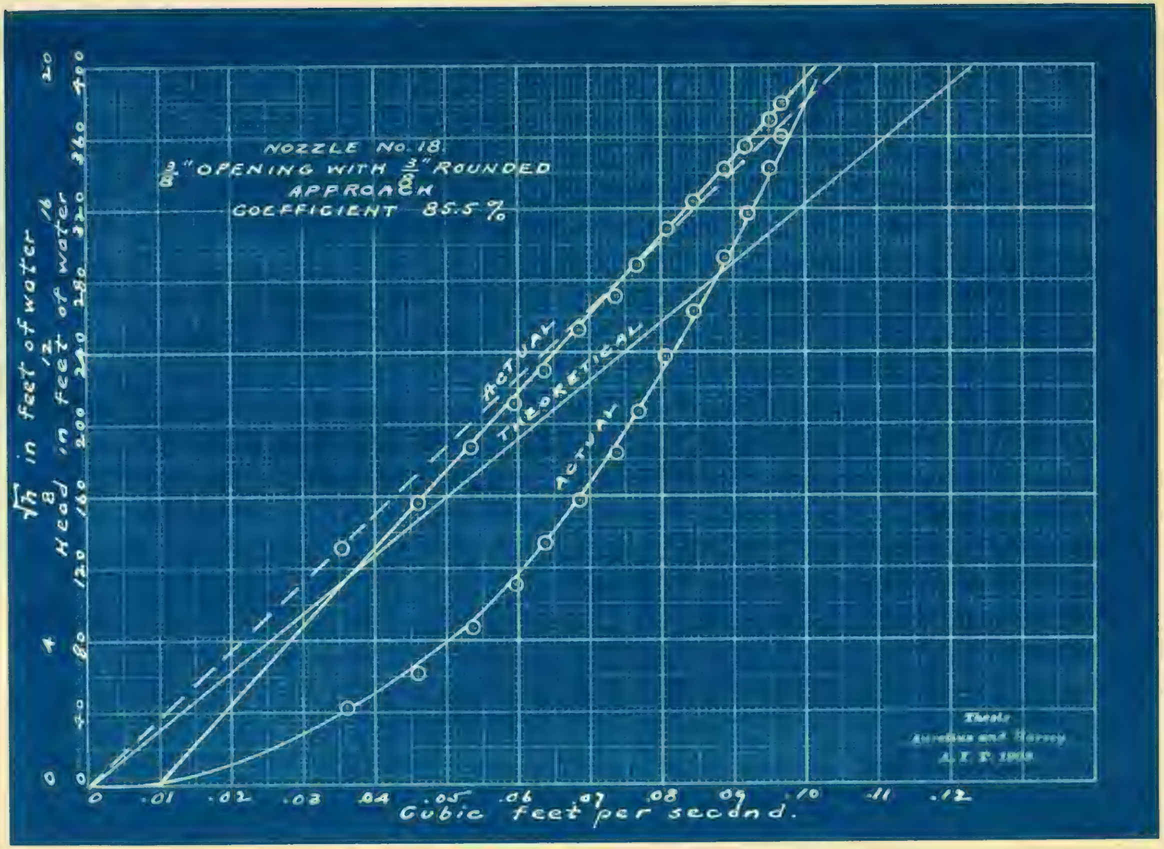
NOZZLE NO.18.

3/8" Opening with 3/8" Rounded Approach

Meter	Hg.	NOZZLE PRESSURE.		DISCHARGE.	
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft/Sec.
1.95	1.395	156.0	360.0	18.96	.0968
1.87	1.368	148.	342.	18.49	.0950
1.75	1.322	1.38	318.	17.84	.0918
1.64	1.279	127.	293.	17.11	.0886
1.48	1.216	113.5	262.	16.19	.0845
1.35	1.161	103.	238.	15.42	.0807
1.21	1.100	90.	207.	14.41	.0765
1.12	1.058	80.	185.	13.60	.0737
.97	.984	68.5	158.	12.57	.0686
.84	.915	57.5	133.	11.53	.0638
.73	.854	48.	111.	10.53	.0598
.58	.762	38.	87.8	9.37	.0535
.42	.647	27.	68.3	7.89	.0457
.25	.500	18.5	42.7	6.53	.0355




NOZZLE No. 18
$\frac{3}{8}$" OPENING WITH $\frac{3}{8}$" ROUNDED
APPROACH
COEFFICIENT 85.5 %
ACTUAL
THEORETICAL
ACTUAL
$\sqrt{h}$ in feet of water
Head in feet of water
0
4
8
12
16
20
0
40
80
120
160
200
240
280
320
360
400
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
Cubic feet per second.
Thesis
Aurelius and Harvey
A. I. T. 1909

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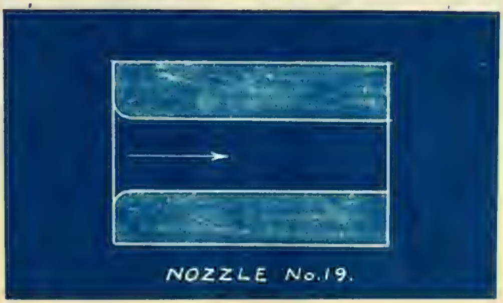
[illegible]

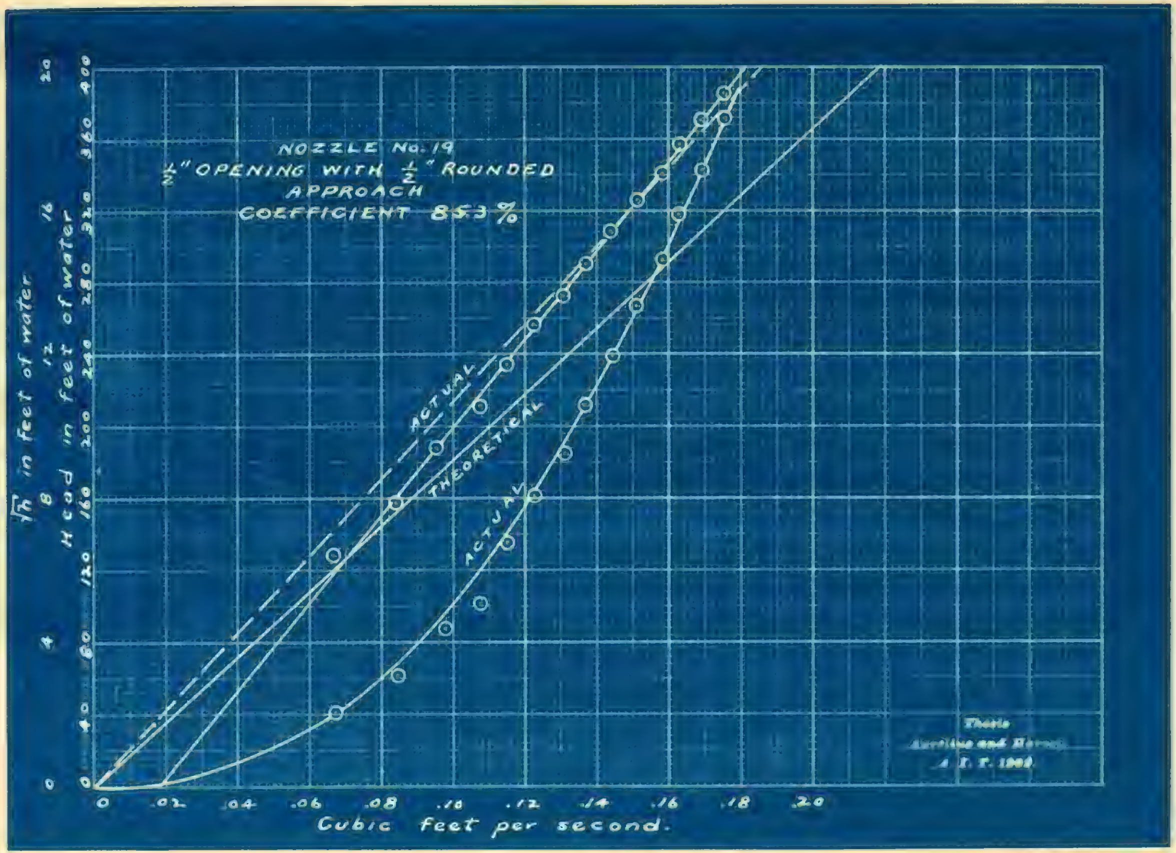
NOZZLE NO.19.

1/2" Opening with 1/2" Rounded Approach

Meter	Hg.	NOZZLE PRESSURE			DISCHARGE.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft./Sec.
6.45	2.535	160.5	372.	19.27	.1752
5.95	2.441	148.	342.	18.49	.1687
5.59	2.360	138.	318.	17.84	.1630
5.23	2.284	127.	293.	17.11	.1580
4.78	2.185	115.	266.	16.31	.1512
4.35	2.084	103.	238.	15.42	.1440
3.91	1.975	91.	210.	14.50	.1365
3.58	1.890	80.	185.	13.60	.1305
3.15	1.774	69.5	161.	12.66	.1227
2.75	1.658	58.5	135.	11.62	.1148
2.41	1.55	48.	111.	10.53	.1075
1.89	1.373	38.	87.8	9.37	.0954
1.46	1.208	27.	62.3	7.89	.0840
.90	.948	17.5	40.4	6.36	.0660



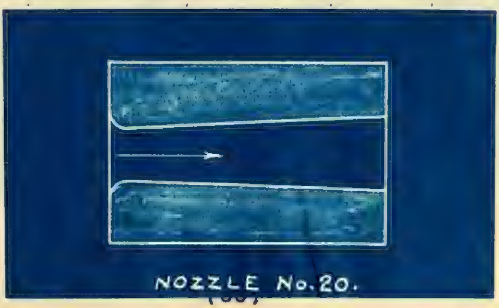
NOZZLE No.19.

NOZZLE No. 19
½" OPENING WITH ½" ROUNDED
APPROACH
COEFFICIENT 85.3 %
ACTUAL
THEORETICAL
ACTUAL
√h in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
Cubic feet per second.
Thesis

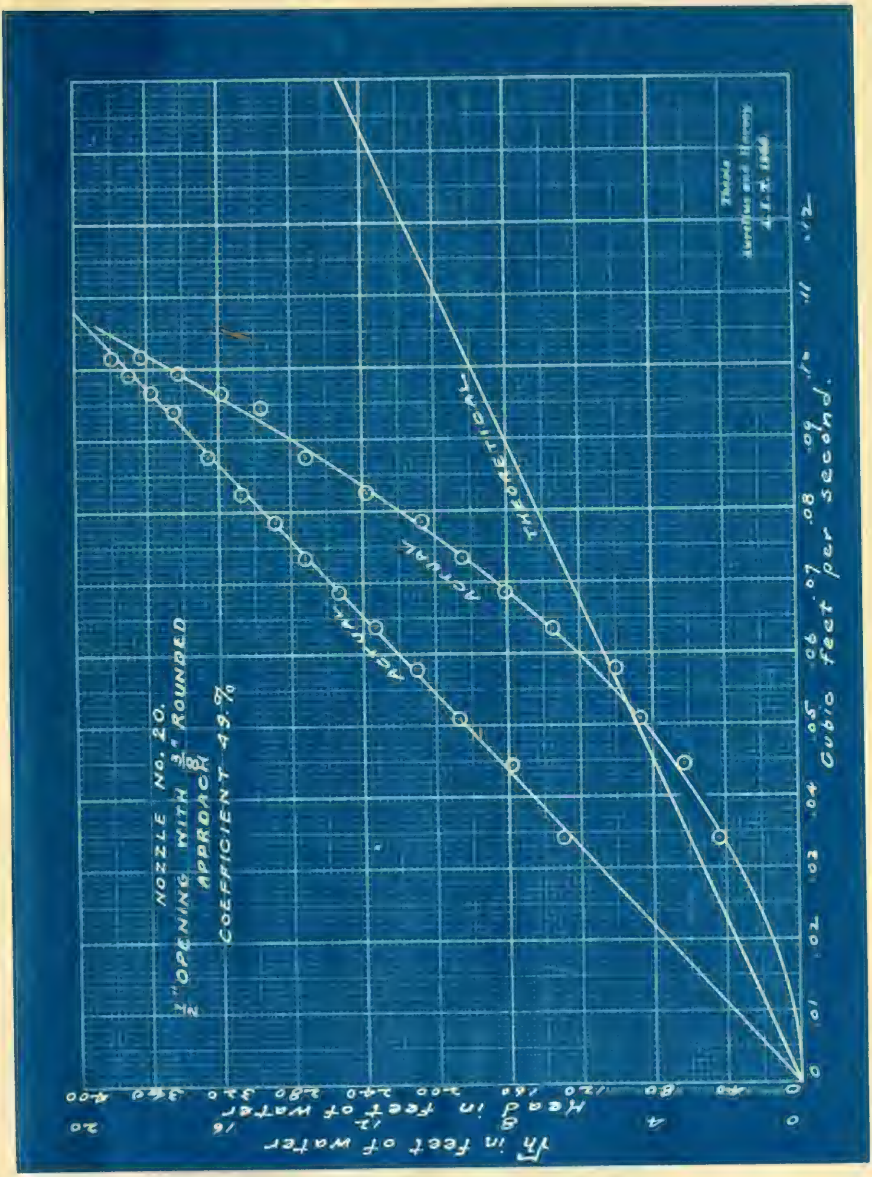
NOZZLE NO.20.

1/2" Opening with 3/8" Rounded Approach

Meter	Hg.	Nozzle Pressure.			Discharge.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft./Sec.
2.13	14.59	157.0	362.0	19.02	.1013
2.04	1.428	148.	342.	18.49	.0990
1.93	1.389	138.	318.	17.84	.0963
1.83	1.352	128.	296.	17.19	.0940
1.59	1.260	115.	266.	16.30	.0875
1.41	1.187	103.	238.	15.42	.0825
1.28	1.130	90.	207.	14.41	.0787
1.11	1.053	80.	185.	13.60	.0733
.97	.984	69.5	161.	12.66	.0686
.84	.915	58.5	135.	11.62	.0638
.68	.824	48.	111.	10.53	.0578
.53	.721	38.	87.8	9.37	.0506
.40	.632	27.	62.3	7.89	.0445
.23	.479	18.5	42.7	6.53	.0340



NOZZLE No. 20.

NOZZLE NO. 20.
1/2" OPENING WITH 3/8" ROUNDED APPROACH
COEFFICIENT 49.%
THEORETICAL
ACTUAL
ACTUAL
Cubic feet per second.
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
Head in feet of water
0
.40
.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
√h in feet of water
0
4
8
12
16
20

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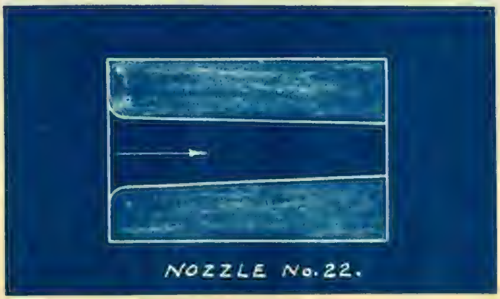
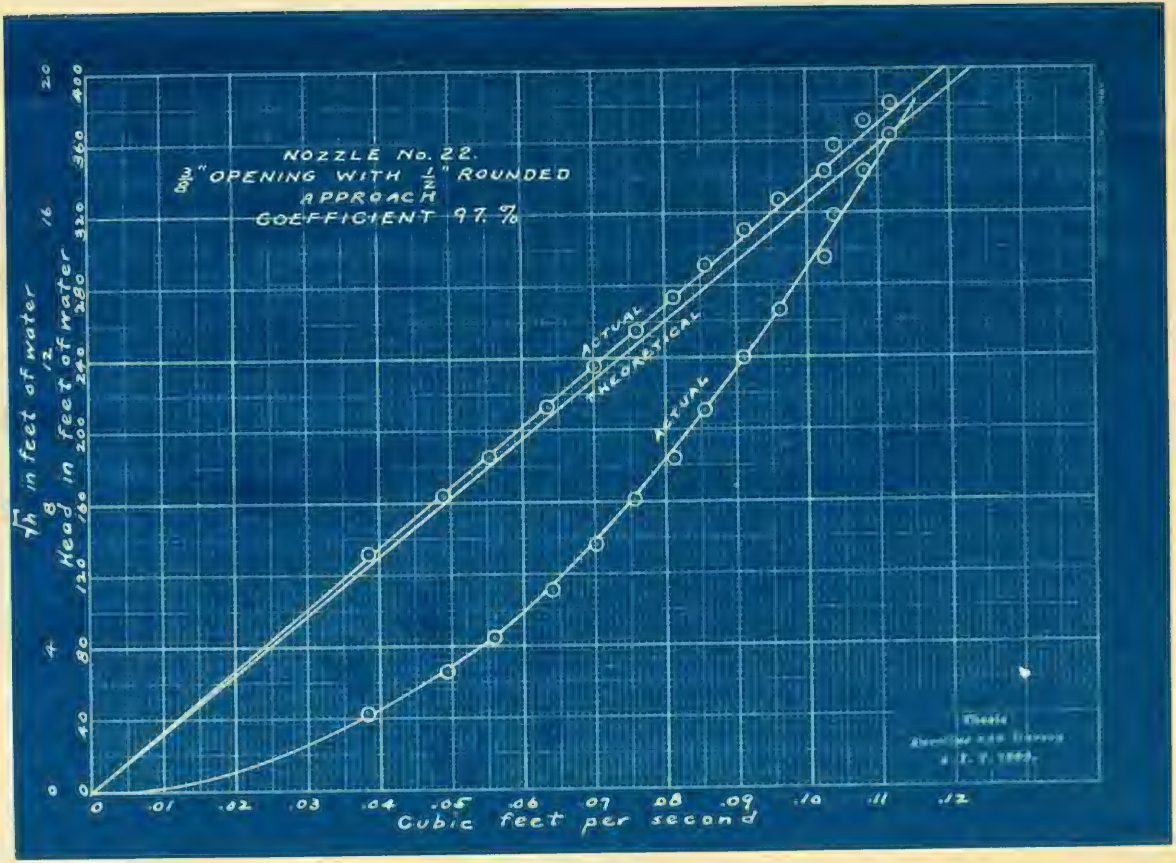
NOZZLE NO. 22.

3/8" Opening with 1/2" Rounded Approach.

Meter	Hg.	Nozzle Pressure.			Discharge.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft/Sec.
2.60	1.613	157.0	362.0	19.03	.1118
2.43	1.560	148.	342.	18.48	.1082
2.25	1.500	138.	318.	17.85	.1040
2.15	1.466	127.	293.	17.12	.1027
1.91	1.382	115.	265.	16.28	.0961
1.72	1.312	103.	237.	15.42	.0912
1.53	1.237	91.	210.	14.50	.0859
1.37	1.171	80.	184.4	13.59	.0815
1.19	1.091	69.5	160.3	12.66	.0760
1.03	1.014	58.5	135.	11.61	.0707
.85	.921	48.	110.4	10.52	.0643
.64	.800	36.5	84.3	9.18	.0560
.50	.707	27.	64.6	8.04	.0498
.30	.548	18.5	42.7	6.54	.0387



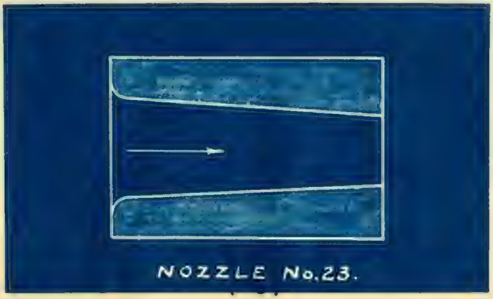
NOZZLE No. 22.


NOZZLE No. 22.
$\frac{3}{8}$" OPENING WITH $\frac{1}{2}$" ROUNDED APPROACH
COEFFICIENT 97. %
ACTUAL
THEORETICAL
ACTUAL
$\sqrt{h}$ in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
Cubic feet per second

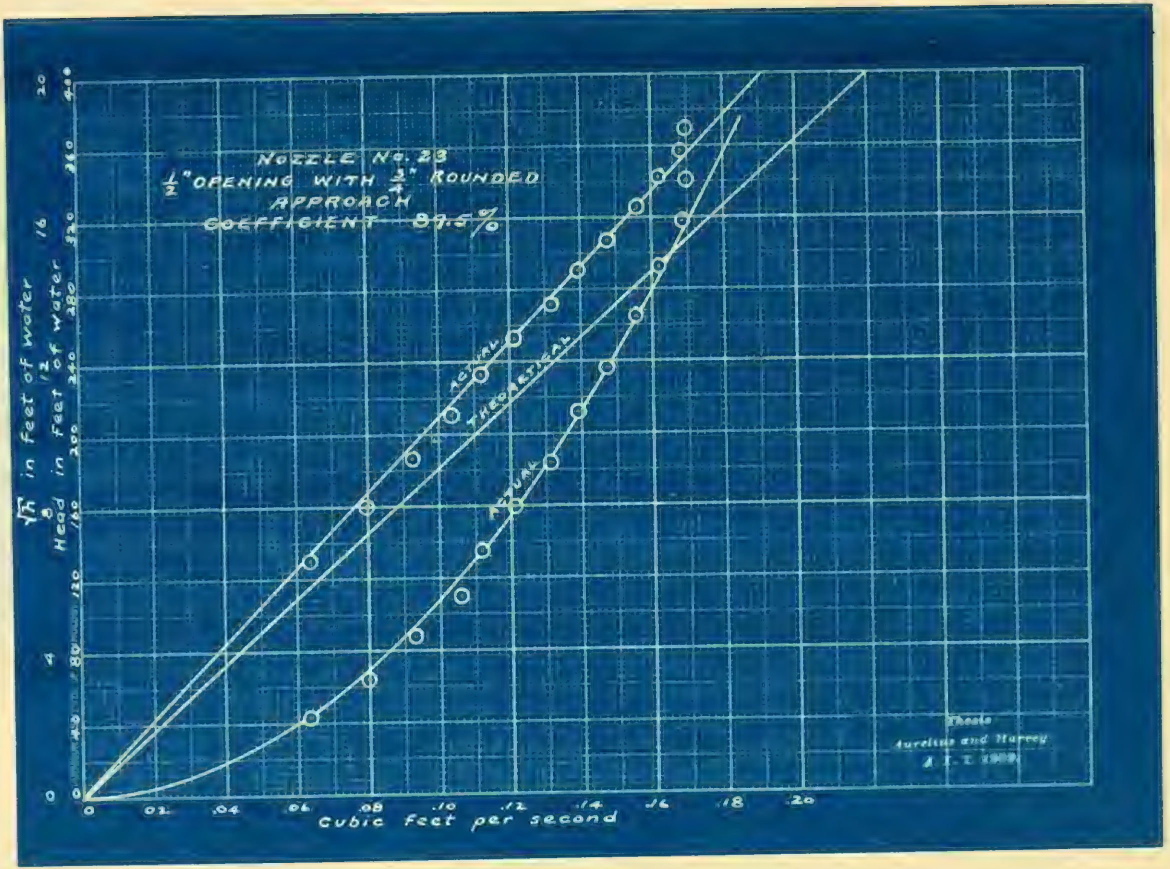
NOZZLE NO.23.

1/2" Opening with 3/4" Rounded Approach.

Meter	Hg.	NOZZLE PRESSURE.			DISCHARGE.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft/Sec.
6.80	2.465	157.0	362.0	19.03	.1703
6.30	2.453	147.5	341.	18.45	.1698
5.92	2.432	138.	318.	17.85	.1681
5.50	2.344	127.	293.	17.12	.1620
5.09	2.255	115.	265.	16.28	.1558
4.55	2.130	103.	237.	15.42	.1472
4.07	2.018	92.	212.	14.56	.1393
3.62	1.900	80.	184.4	13.59	.1315
3.10	1.760	69.5	160.3	12.66	.1217
2.62	1.617	58.5	135.	11.61	.1120
2.24	1.497	48.	110.4	10.52	.1038
1.76	1.326	38.	87.8	9.36	.0922
1.32	1.148	27.	64.6	8.04	.0798
.84	.915	18.5	42.7	6.55	.0638



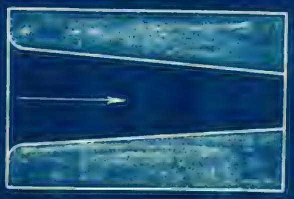
NOZZLE No.23.


NOZZLE No. 23
$\frac{1}{2}$" OPENING WITH $\frac{3}{4}$" ROUNDED APPROACH
COEFFICIENT 89.5%
ACTUAL
THEORETICAL
ACTUAL
$\sqrt{h}$ in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
Cubic feet per second
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
Thesis
Aurelius and Harvey
A. I. T. 1909

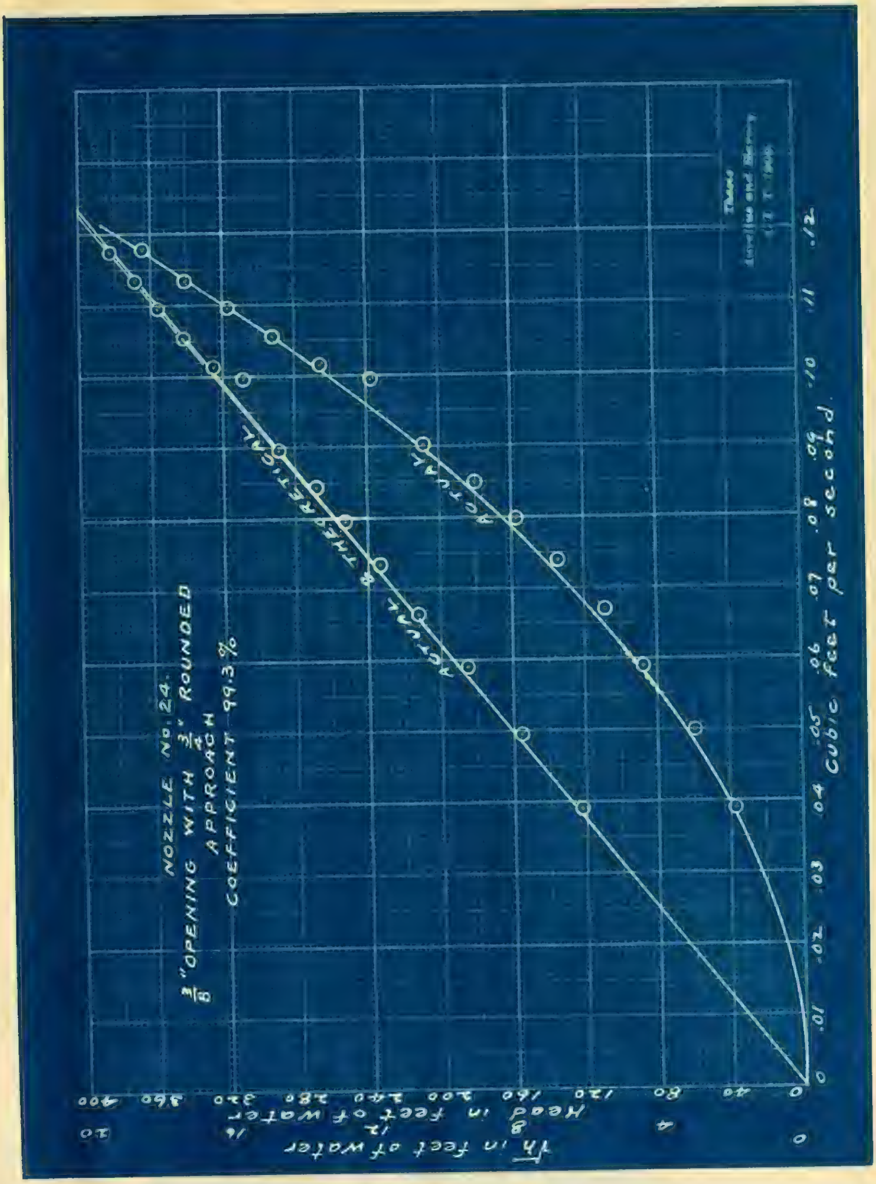
NOZZLE NO. 24.

3/8" Opening with 3/4" Rounded Approach.

Meter	Hg.	NOZZLE PRESSURE.			DISCHARGE.
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft/Sec.
2.88	1.698	158.0	365.0	19.10	.1175
2.67	1.633	147.5	341.	18.45	.1132
2.49	1.579	138.	318.	17.85	.1094
2.29	1.514	127.	293.	17.12	.1052
2.13	1.461	115.	265.	16.28	.1013
1.87	1.368	103.	237.	15.42	.0950
1.67	1.292	91.	210.	14.51	.0898
1.47	1.212	78.5	181.	13.46	.0843
1.30	1.141	69.5	160.3	12.66	.0793
1.12	1.058	58.5	135.	11.61	.0737
.91	.953	48.	110.4	10.52	.0665
.71	.843	38.	87.8	9.36	.0589
.50	.707	26.	60.0	7.75	.0497
.30	.548	16.5	38.0	6.17	.0387



NOZZLE No.24.


NOZZLE No. 24.
3/8" OPENING WITH 3/4" ROUNDED
APPROACH
COEFFICIENT 99.3%
ACTUAL
ACTUAL & THEORETICAL
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
Cubic feet per second
0
40
80
120
160
200
240
280
320
360
400
Head in feet of water
0
4
8
12
16
20
√h in feet of water
Thesis

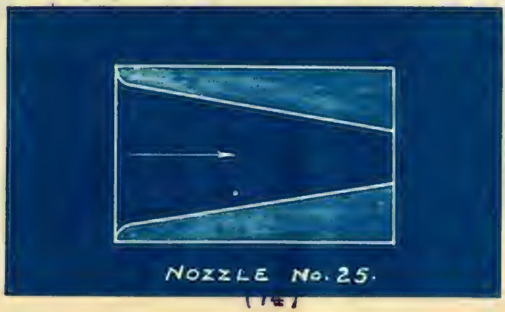
[illegible]

ILLUSTRATIONS OF [illegible]

NOZZLE NO.25.

/3/8" Opening with 1"Rounded Approach.

Meter	Hg.	NOZZLE PRESSURE.			DISCHARGE.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft/Sec.
2.13	1.657	158.0	364.0	19.08	.1013
1.98	1.408	149.	343.	18.52	.0979
1.87	1.370	139.	321.	17.90	.0950
1.70	1.305	127.	293.	17.12	.0907
1.57	1.253	115.	265.	16.27	.0872
1.40	1.183	104.	240.	15.50	.0823
1.21	1.100	90.	207.	14.40	.0765
1.09	1.043	78.5	181.	13.46	.0728
.97	.984	69.5	160.3	12.66	.0685
.81	.900	58.5	135.	11.62	.0630
.65	.806	48.	110.8	10.52	.0565
.51	.714	37.	85.4	9.24	.0502
.39	.625	27.	62.3	7.88	.0440
.24	.490	17.5	40.4	6.35	.0348



NOZZLE No. 25.

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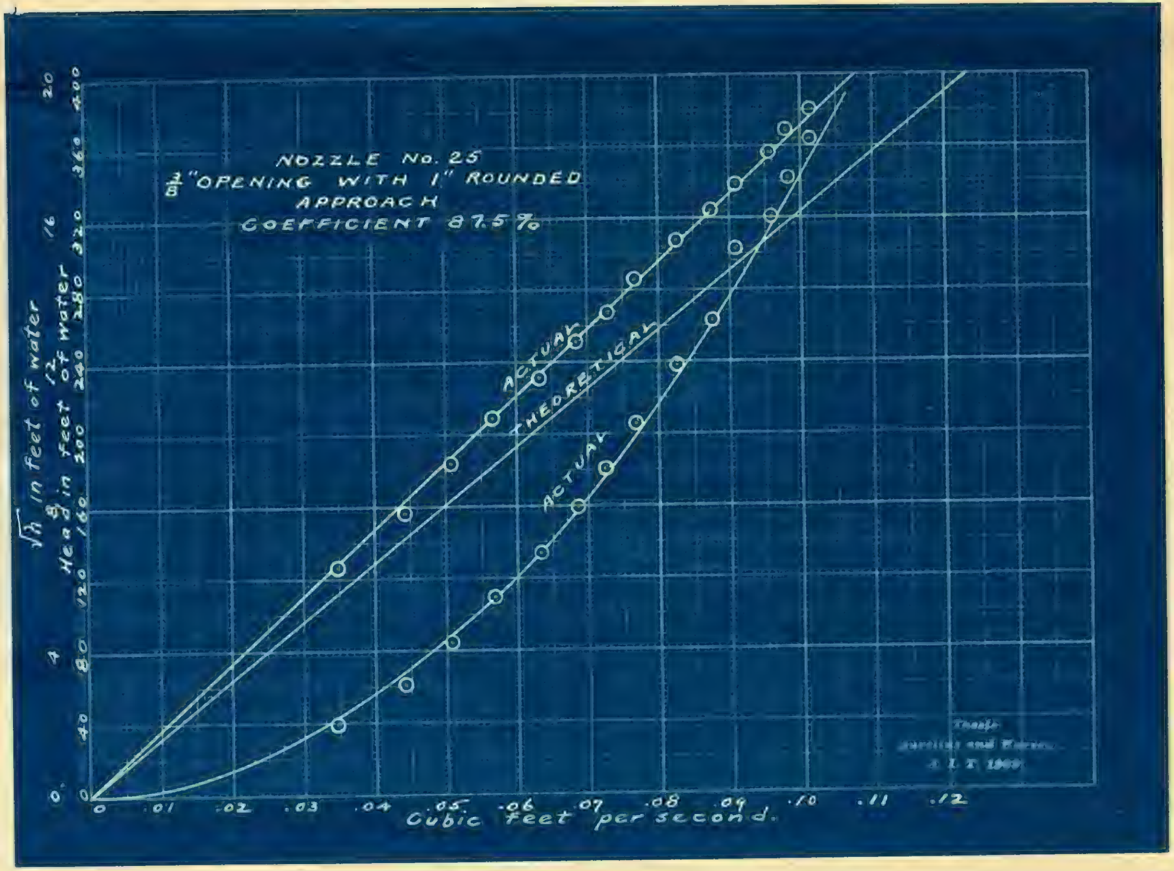
LIBRARY.

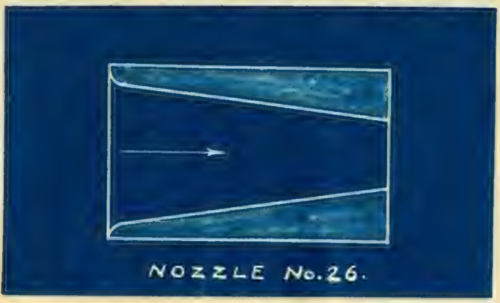

NOZZLE No. 25
$\frac{3}{8}$" OPENING WITH 1" ROUNDED
APPROACH
COEFFICIENT 87.5%
ACTUAL
THEORETICAL
ACTUAL
$\sqrt{h}$ in feet of water
Head in feet of water
Cubic feet per second.
0.
4
8
12
16
20
0
.40
.80
120
160
200
240
280
320
360
400
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
Thesis

INSTITUTE OF TECHNOLOGY

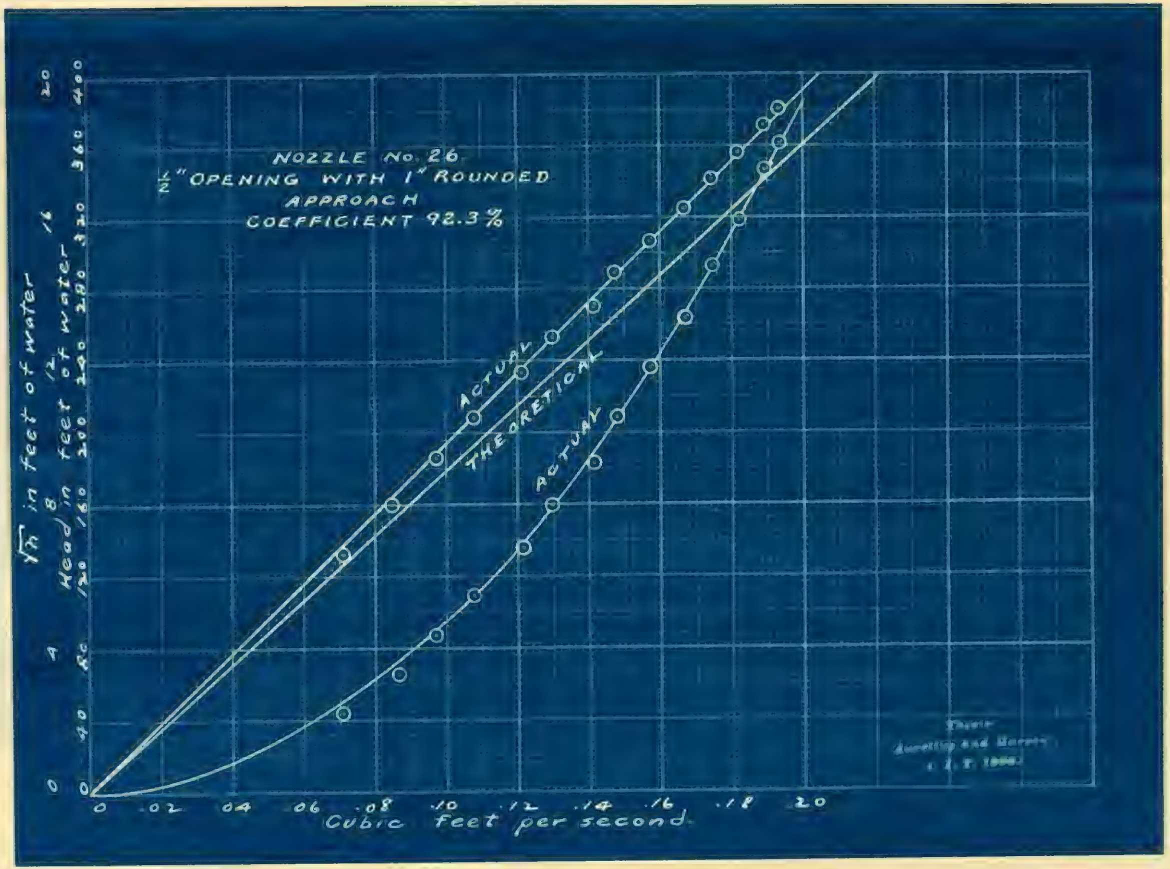
NOZZLE NO.26.

1/2" Opening with 1" Rounded Approach.

Meter	Hg.	NOZZLE PRESSURE.			Discharge.
h	$\sqrt{h}$	#/Sq.in.	Ft.H_2O	$\sqrt{h'}$	Cu.ft/ Sec.
7.82	2.797	157.0	362.0	19.02	.1932
7.50	2.738	150.	347.	18.60	.1892
6.90	2.627	138.	318.	17.84	.1816
6.37	2.524	127.	293.	17.11	.1745
5.83	2.415	115.	265.	16.27	.1668
5.16	2.270	103.	237.5	15.41	.1568
4.56	2.135	91.	210.	14.49	.1475
4.14	2.034	80.	184.4	13.58	.1406
3.52	1.876	69.5	160.3	12.66	.1297
3.03	1.744	59.5	137.	11.71	.1208
2.41	1.552	48.	110.8	10.52	.1078
1.95	1.396	38.	87.8	9.37	.0970
1.49	1.220	28.	64.7	8.04	.0848
1.04	1.020	19.5	45.	6.70	.0710



NOZZLE No.26.



NOZZLE No. 26
$\frac{1}{2}$" OPENING WITH 1" ROUNDED APPROACH
COEFFICIENT 92.3%

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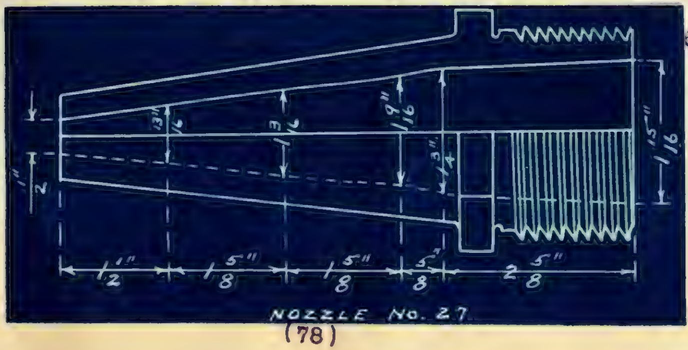
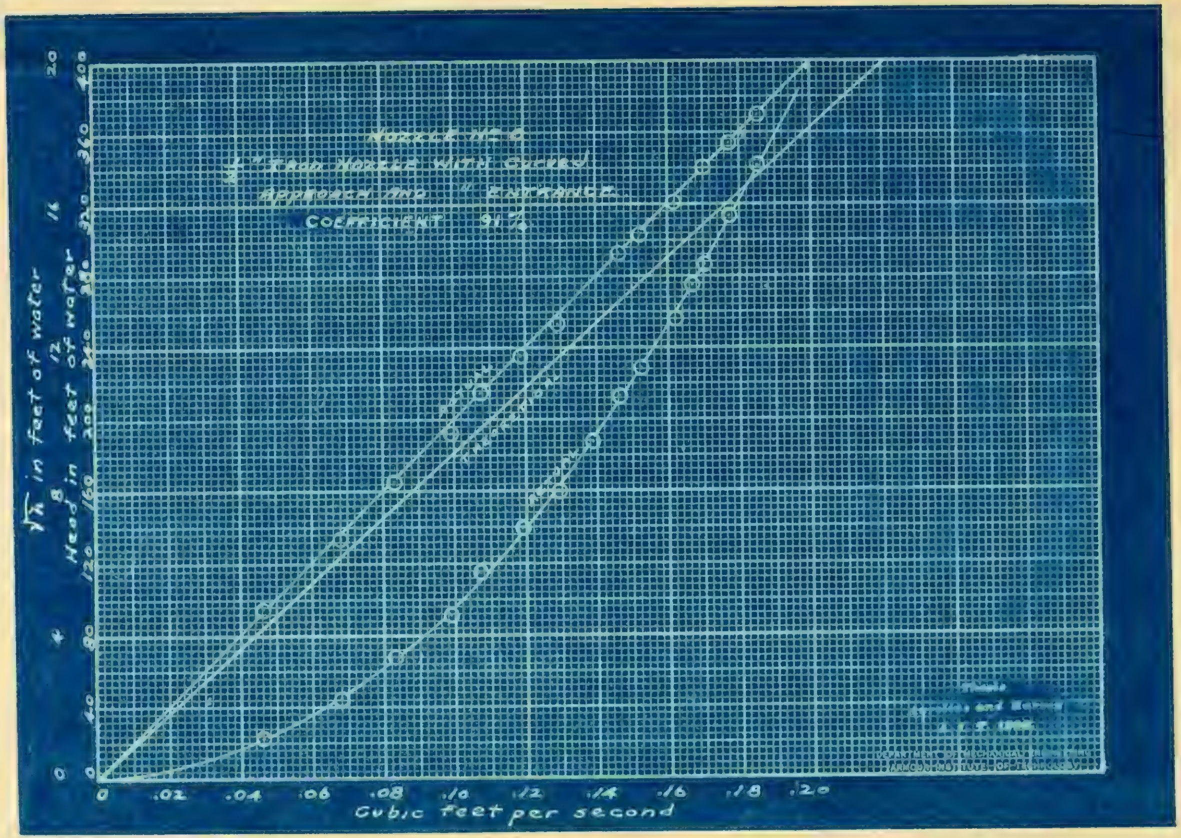
NOZZLE NO.27.

1/2" Iron Nozzle.

Meter.	Hg.	Nozzle Pressure			Discharge.
h	$\sqrt{h}$	#/sq.in.	Ft.H_2O	$\sqrt{h}$	Cu.ft./Sec.
7.25	2.689	148.0	341.7	18.46	.1858
6.62	2.571	136.	314.	17.70	.1776
6.12	2.471	126.	290.8	17.05	.1707
5.88	2.421	120.	277.	16.62	.1674
5.52	2.348	111.	256.1	16.00	.1623
4.85	2.200	99.5	229.6	15.13	.1520
4.48	2.116	91.5	211.1	14.52	.1464
4.02	2.020	82.	189.3	14.08	.1397
3.48	1.865	70.	161.2	12.69	.1290
2.96	1.720	60.	138.5	11.75	.1190
2.40	1.547	50.	115.5	10.73	.1073
1.88	1.370	40.	92.4	9.51	.0950
1.43	1.194	29.5	68.1	8.25	.0830
.96	.980	19.5	45.	6.70	.0683
					61



NOZZLE NO. 27


NOZZLE No. 6
¼" Iron Nozzle with Curved
Approach and ¼" Entrance
COEFFICIENT 91%
ACTUAL
THEORETICAL
ACTUAL
$\sqrt{h}$ in feet of water
0
4
8
12
16
20
Head in feet of water
0
40
80
120
160
200
240
280
320
360
400
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
Cubic feet per second
Department of Mechanical Engineering
Armour Institute of Technology

ARMOUR
INSTITUTE OF TECHNOLOGY
[illegible]

PART 3.

COMPARATIVE DISCUSSION
of
COEFICIENTS OF EFFLUX.

The coeficients of efflux obtained in these tests are arranged in Table (1), according to their degree of efficiency. Apparently the best coeficient obtained was 99.3%. This figure, although placed in the table, is undoubtedly erroneous. Friction alone, provided all other conditions were perfect in this form of nozzle, would limit the best to be expected at about 98.%.

Disregarding the first then, the best coeficient obtained is 97.3%. This is for a nozzle having an angle of convergence of 14°40' with inner edges not rounded. As will be shown later it would be possible to even increase this by rounding the approach.

TABLE NO.I.

Nozzle Number	SIZE		ANGLE	COEFICIENT.
24	3/8 X 3/4	R.	11°0'	99.3 %
14	1/4 X 3/4		14°40'	97.3
22	3/8 X 1/2	R.	3°40'	97.0
2	3/8 X 1/2		3°40'	96.0
12	3/8 X 3/4		11°0'	95.0
1	1/4 X 1/2		7°40'	94.1
26	1/2 X 1	R	14°40'	92.3
16	1/2 X 1		14°40'	91.3
23	1/2 X 3/4	R	7°20'	89.5
13	1/2 X 3/4		7°20'	88.8
17	1/4 X 1/4	R	0°	88.7
25	3/8 X 1	R	18°40'	87.5
18	3/8 X 3/8	R	0°	85.5
19	1/3 X 1/2	R	0°	85.3
15	3/8 X 1		18°40'	81.0
5	1/4 X 1/4		0°	72.8
4	3/8 X 3/8		0°	67.4
20	1/2 X 3/8	R	3°40'	49.0
8	3/4 X 1/2	R	7°20'	37.4
2 a	1/2 X 3/8		3°40'	35.1
3	1/2 X 1/2		0°	30.0
13 a	3/4 X 1/2		7°20'	24.9
9	3/4 X 3/8	R	11°0'	22.0
6	1/2 X 1/4	R	7°20'	21.0
11	1 X 1/2	R	14°40'	20.75
1 a	1/2 X 1/4		7°20'	16.65
16 a	1 X 1/2		14°40'	16.4
12 a	3/4 X 3/8		11°0'	16.0
10	1 X 3/8	R	18°40'	14.0
7	3/4 X 1/4	R	14°40'	11.9
15 a	1 X 3/8		18°40'	8.55
14 a	3/4 X 1/4		14°40'	7.0

Regardless of taper or size the coeficient of the nozzle was increased by rounding the inner edges. The rounding has the effedt of eliminating the contraction of the flow at entrance, thus filling up the tube. Naturally, the increase in the cross section of the stream increases the discharge. This increased the discharge for the same size nozzle improves the coeficient.

The nozzles of the straight bore are the best examples of this effect. The three sizes calibrated were as follows:-

1/4" nozzle increased from 72.8% to 88.7%.
3/8" " " " 67.4% '' 85.5%.
1/2" " " " 30.0% '' 85.3%.

The increases were respectively, 5.9%, 18.1% and 55.3%. It would seem evident from these results, although they are most too few as a basis for an assumption, that an increase in the diameter of the straight bore is accompanied by a decrease in the coeficient.

From a 1/4" to a 1/2" nozzle there is a drop from 72.8% to 30.0%. With the edges rounded however, the coeficient is practically the same for all three sizes. This would indicate that for a larger bore, but for constant head, the contraction of the stream at entrance is greater.

The nozzles may be grouped according to the size of outlet as 1/4", 3/8", 1/2" and 1" nozzles; all being one and fifteen sixteenths inches long. Their coeficients are based on the discharge through an orifice equal in cross section to the outlet of the nozzle.

Table 2.

1/4" Nozzles.

Size		Angle	Coeficient.
1/4" X 3/4"		14°40'	97.3%
1/4" X 1/2"		7°20'	94.1%
1/4" X 1/4"	R	0°	88.7%
1/4" X 1/2"		0	72.8%

A maximum coeficient is attained with an angle of convergence of 14°40'. As stated before, this could be improved by rounding the inner edges.

Both converging nozzles of this size are better than the straight bore.

TABLE 3

3/8" Nozzles.

Size	Angle	Coeficient
3/8"X 3/4" R	11°	99·3%
3/8" X 1/2" R	3°40'	97. %
3/8" X 1/2"	3°40'	96.
3/8" X 3/4"	11°	95. %
3/8" X 1" R	18°40'	87.5%
3/8" X 3/8" R	0°	85.5%
3/8" X 1"	18°40'	81. %
3/8" X 3/8"	0°	67.4%

The converging nozzles of this size also have the best coeficient. There is a greater range in the angle of convergence than there is for the 1/4" nozzles. This range presents the effect of indefinitely increasing the angle of convergence. Considering only the converging nozzles 11° gives the best and 18°40' the poorest coeficient.

Somewhere between 11° and 18°40' is evidently the best value for the angle. Any increase or decrease from this value lowers the coeficient.

TABLE 4.

1/2" Nozzles.

Size	Angle.	Coeficient.
1/2" X 1" R	14°40'	92.3 %
1/2" X 1"	14°40'	91.3 %
1/2" X 3/4" R	7°20'	89.5 %
1/2" X 3/4"	7°20'	88.8 %
1/2" X 1/2 R	0°	85.3 %
1/2" X 3/8 R	3°40'	49. %
1/2" X 3/8"	3°40'	35.1%
1/2" X 1/2"	0°	30. %
1/2" X 1/4" R	7°20'	21. %
1/2" X 1/4"	7°20'	16.65%

This size passes from the converging through the straight bore to the diverging nozzle. Again, the converging nozzles have the best coeficient. A maximum of 92.3% is reached for an angle of 14°40' which is the same angle as was found with the 1/4" nozzle.

THere is a continual dropping off in the coeficient as the angle decreases until 0° is reached, which is the straight bore. From here on, the nozzle is diverging and as the angle of divergence increases the coefficient continues to decrease. A rounding of the inner edges also improves these nozzles. The increase in coefficient is more marked for the diverging than for the converging. In the former there is as much as 14% increase while the latter continues only about 1.%.

TABLE 5.

3/4" Nozzles.

Size	Angles	Coefficient.
3/4" X 1/2" R	7°20'	37.4%
3/4" X 1/2"	7°20'	24. 9%
3/4" X 3/8" R	11°	22.%
3/4" X 3/8"	14°40'	16.%
3/4" X 1/4" R	14°40'	11.9%
3/4" X 1/4"	14°40'	7.%

This size only affords examples of diverging nozzles. The least angle of divergence with the inner edges rounded gives the best coefficient, while the greatest angle gives the poorest coefficient.

The results, thoggh rather incomplete, are quite consistent with the results obtained from the other sizes. The rounding of the edges of these diverging nozzles greatly increased the coefficient.

TABLE 6.

1" Nozzles.

Size		Angle	Coefficient.
1" x 1/2"	R	14°40'	20.75%
1" x 1/2"		14°40'	16.4
1" x 3/8"	R	18°40'	14. %
1" x 3/8"		18°40'	8.55%

Again the angle of convergence of 14°40' appears in producing the best coefficient. The decrease in the coefficient accompanying an increase in the angle beyond 14°46' is also illustrated in these nozzles. The rounding of the inner edges has about the same affect as was brought out in the other sizes.

All the examples show quite clearly that a rounding of the inner edges of the nozzle improves the coefficient. This effect is most pronounced in the nozzle of straight bore and increases as the diameter increases. In the diverging nozzle the effect is not quite as great as in the nozzle of straight bore but more marked than in the converging nozzle.

Beginning with a widely diverging nozzle as the angle decreases to 0° the coefficient increases. After passing through Zero the nozzle becomes converging and as the angle increases the coefficient increases. This increase continues until an angle of 14° 40' is reached. Any increase beyond this value causes a decrease in the coefficient. From this it is evident that the converging nozzle with an angle of 14° 40' is the most efficient.